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INSTITUTIONAL AND ADMINISTRATIVE IMPEDIMENTS TO GOVERNMENT POLICY IMPLEMENTATION BY COOPERATIVE SOCIETIES

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ABSTRACT: ***In translating government policies into grassroots-level outcomes, cooperative societies are very important, especially in the areas of agriculture, credit, housing, and social welfare. Although they are strategically important, cooperative societies usually have to deal with very large institutional and administrative obstacles that prevent the proper and smooth implementation of policies. Among these challenges are the wastage of time and resources due to bureaucracy, poor governance, lack of independence, political meddling, complex regulations, and lack of skilled managers. The research at hand aims to analyze the institutional and administrative barriers that affect the implementation of government policies by cooperatives in terms of their nature and extent. Through the analysis of organizational frameworks, administrative practices, and policy methods, the research intends to determine the main constraints and recommend measures to improve institutional efficiency and administrative effectiveness. The outcomes of this research will probably lead to better policy implementation, enhanced cooperative governance, and more efficient public service delivery.***

KEYWORDS: *Cooperative Societies, Government Policy Implementation, Institutional Impediments, Administrative Challenges, Governance and Management*

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1. INTRODUCTION

Government policies basically aim at supporting socio-economic development, inclusive growth, and public welfare. The cooperative societies, by reason of their democratic structure and people-centered approach, are the main institutional mechanisms wherein these policies are executed by the government at the local and community levels. They work as the bridge between the state and the beneficiaries, assuring that the policy gains are efficiently distributed among the targeted populations. However, the successful implementation of government policies via cooperative societies is frequently limited by a variety of institutional and administrative obstacles. Poorly established governance frameworks, duplicate regulations, little autonomy in decision-making, lack of trained personnel, and over-management through bureaucracy all take their toll on the efficiency of cooperative societies. Moreover, delays in administration, poor communication among government departments and political interference all aggravate the situation of policy execution. Being cognizant of these roadblocks is crucial for making cooperative institutions stronger and increasing their ability to act as efficient policy implementation agents. The research herein, thus, is concentrated towards looking into the institutional and administrative issues that the cooperatives face in government policies' implementation and calling for reforms in both structures and administration.

2. STATEMENT OF THE PROBLEM

Even though cooperative societies are the ones responsible for running many government policies and social schemes, a lot of them do not meet the targets. The disconnection between the making of the policy and the actual implementation is mainly due to the weaknesses of the institutions and the inefficiencies of the administration in the cooperative societies. The lack of effective governance, the interference of the government, the unprofessional management, the rigidity of the procedures, and the poor accountability systems are some of the issues that have weakened their power. These problems not only take time in implementing the policies but also lessen the government initiative's intended impact leading to resource misallocation and lowering the public's trust. The co-operative societies' role is very important but still, very little empirical research has been done to properly study the institutional and administrative barriers that affect the implementation of policies. Therefore, it is necessary to detect, analyze, and solve these problems for the betterment and sustainability of the cooperative societies.

3. NEED AND SIGNIFICANCE OF THE STUDY

The government's grassroots level policies especially in sectors such as agriculture, credit, housing, and social welfare are majorly dependent on cooperative societies. These societies, however, are not only significant but also many of them suffer from institutional weaknesses, poor administration, and operational challenges that prevent effective policy implementation. Knowing these problems will not only increase the effectiveness of the policy but also strengthen governance, utilize resources better, and increase public trust. This study is important because it reveals the main institutional and administrative barriers, suggests ways to enhance efficiency and management skills, and adds to the academic comprehension of cooperative operations which in turn will be a support for inclusive socio-economic development.

4. OBJECTIVES OF THE STUDY

i. To examine the institutional framework governing cooperative societies in relation to government policy implementation.
ii. To identify the major administrative impediments affecting policy execution by cooperative societies.

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iii. To analyze the impact of governance, management, and regulatory factors on policy implementation efficiency.
iv. To assess the role of government supervision and political intervention in the functioning of cooperative societies.
v. To suggest measures for improving institutional capacity and administrative effectiveness in cooperative societies.

5. HYPOTHESES OF THE STUDY

1. **H_{01}:** There is no significant relationship between institutional factors and the implementation of government policies by cooperative societies.
2. **H_{02}:** Administrative inefficiencies do not have a significant impact on the effectiveness of government policy implementation by cooperative societies.
3. **H_{03}:** Government control and political interference do not significantly affect the operational autonomy of cooperative societies in implementing policies.
4. **H_{04}:** The level of managerial competence and availability of skilled personnel have no significant influence on policy implementation by cooperative societies.
5. **H_{05}:** Governance structure and regulatory framework do not significantly influence the performance of cooperative societies in executing government policies.

6. METHODOLOGY

The research employs a descriptive and analytical methodology to investigate the institutional and administrative barriers that hinder the successful implementation of government policies through the cooperative sector. The research is empirical and relies on primary as well as secondary data. A structured questionnaire is used to collect primary data from selected cooperative societies' managers, secretaries, and board members based on a five-point Likert scale. Government reports, cooperative department publications, journals, and relevant books are the sources of secondary data. A stratified random sampling technique is applied to recruit the respondents from various types of cooperative societies, thus guaranteeing good representation. The data gathered are coded, tabulated, and analyzed using SPSS with application of the statistical tools of percentage analysis, correlation, and regression analysis to test the null hypotheses formulated and consequently reach significant conclusions.

7. DATA ANALYSIS & INTERPRETATION

Objective 1: Examine the institutional framework governing cooperative societies in relation to government policy implementation

Hypothesis H_{01}: There is no significant relationship between institutional factors and the implementation of government policies by cooperative societies.

Table 1: Correlation (Objective 1)

Variable	Policy Implementation	Institutional Factors
Policy Implementation	1	0.563**
Institutional Factors	0.563**	1
N	120	120

Significance: $p < 0.01$

Interpretation:

The correlation ($r = 0.563$, $p < 0.01$) indicates a strong positive relationship between institutional factors and policy implementation. **H_{01} is rejected**, showing that a strong institutional framework enhances the effectiveness of government policy execution.

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Objective 2: Identify the major administrative impediments affecting policy execution

Hypothesis H_{02}: Administrative inefficiencies do not have a significant impact on policy implementation.

Table 2: Correlation (Objective 2)

Variable	Policy Implementation	Administrative Inefficiencies
Policy Implementation	1	0.612**
Administrative Inefficiencies	0.612**	1
N	120	120

Significance: $p < 0.01$

Interpretation:

Administrative inefficiencies show the strongest positive correlation ($r = 0.612$, $p < 0.01$) with policy implementation, confirming that procedural and managerial delays are major obstacles. **H_{02} is rejected.**

Objective 3: Analyze the impact of governance, management, and regulatory factors

Hypotheses H_{04} & H_{05}:

- H_{04}: Managerial competence has no significant influence on policy implementation.
- H_{05}: Governance structure and regulatory framework do not significantly influence policy implementation.

Table 3: Correlation (Objective 3)

Variable	Policy Implementation	Managerial Competence	Governance & Regulatory Framework
Policy Implementation	1	0.489**	0.541**
N	120	120	120

Significance: $p < 0.01$

Interpretation:

Both managerial competence ($r = 0.489$) and governance structures ($r = 0.541$) positively correlate with policy implementation. **H_{04} and H_{05} are rejected**, suggesting that skilled personnel and strong governance mechanisms are critical for effective policy execution.

Objective 4: Assess the role of government supervision and political interference

Hypothesis H_{03}: Government control and political interference do not significantly affect the operational autonomy of cooperative societies.

Table 4: Correlation (Objective 4)

Variable	Policy Implementation	Government Control
Policy Implementation	1	0.489**
N	120	120

Significance: $p < 0.01$

Interpretation:

Government control and political interference have a moderate positive correlation with policy implementation ($r = 0.489$, $p < 0.01$), indicating that excessive supervision may affect operational autonomy. **H_{03} is rejected.**

Objective 5: Suggest measures for improving institutional capacity and administrative effectiveness

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Regression

Dependent Variable: Policy Implementation

Independent Variables: Institutional Factors, Administrative Inefficiencies, Managerial Competence, Governance, Government Control

Table 5: Test Result

Model	R	R^2	Adjusted R^2	F	Sig.
1	0.758	0.574	0.560	38.45	0.000**

Interpretation:

- $R^2 = 0.574 \rightarrow$ 57.4% of the variance in policy implementation is explained by the independent variables.
- $F = 38.45$, $p < 0.01 \rightarrow$ the model is statistically significant.
- Regression confirms that improving institutional, administrative, managerial, and governance factors significantly enhances policy implementation.

Table 6: Demographic Profile of respondents

Particulars	Category	No. of Respondents	Percentage (%)
Gender	Male	78	65%
	Female	42	35%
Age	Below 30 years	18	15%
	30–40 years	36	30%
	40–50 years	42	35%
	Above 50 years	24	20%
Designation	Manager	46	38.3%
	Secretary	40	33.3%
	Board Member	34	28.4%
Experience	Below 5 years	26	21.7%
	5–10 years	44	36.6%
	Above 10 years	50	41.7%

8. FINDINGS

The study employed descriptive statistics, correlation, and regression analyses to examine the impact of institutional and administrative factors on the implementation of government policies by cooperative societies in Kollam district.

1. **Institutional Factors:**
   The correlation analysis revealed a strong positive relationship ($r = 0.563$, $p < 0.01$) between institutional factors and policy implementation, indicating that societies with well-defined structures, roles, and internal governance mechanisms implement government programs more effectively. Strong institutional frameworks positively influence the successful implementation of government policies
2. **Administrative Inefficiencies:**
   Administrative inefficiencies exhibited the highest positive correlation with policy implementation ($r = 0.612$, $p < 0.01$), highlighting that procedural delays, lack of streamlined processes, and managerial shortcomings significantly hinder policy execution. Administrative inefficiencies are the most significant barrier to effective policy execution
3. **Government Control and Political Interference:**
   A moderate positive correlation ($r = 0.489$, $p < 0.01$) was observed between government control/political interference and policy implementation, suggesting that excessive supervision and political intervention can constrain operational autonomy and reduce effectiveness. Excessive

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government control and political interference can hinder operational autonomy and reduce the effectiveness of cooperative societies.

4. **Managerial Competence:**
   The analysis demonstrated that managerial competence ($r = 0.489$, $p < 0.01$) is a significant determinant of policy implementation, emphasizing the need for skilled personnel in key positions for efficient execution of government schemes. Managerial competence and skilled personnel are crucial for efficient policy implementation
5. **Governance and Regulatory Framework:**
   Governance structures and regulatory clarity were positively correlated with policy implementation ($r = 0.541$, $p < 0.01$), underlining the importance of transparent and robust governance mechanisms for achieving desired policy outcomes. Governance structures and regulatory clarity enhance performance and ensure accountability. Overall, institutional, administrative, managerial, governance, and political factors together significantly impact the execution of government policies, explaining over half of the variance in policy outcomes.

9. SUGGESTIONS

Taking into account the examination of institutional and administrative barriers that the cooperative sector has to deal with while executing government policies, a few recommendations have been made that would lead to their higher impact::

i. **Strengthen Institutional Framework:** The cooperative societies should have a clear delineation of roles, responsibilities, and accountability, and they should carry out periodic reviews of their internal processes for the purpose of ascertaining efficiency and transparency.
ii. **Enhance Administrative Efficiency:** Administrative procedures should be simplified, and the adoption of modern management practices should be done in order to eliminate delays and improve the execution of policies.
iii. **Develop Managerial Competence:** Regular training and capacity-building programs should be made mandatory for the managers, secretaries, and board members, and recruitment of qualified personnel should be done in order to professionalize management further.
iv. **Promote Good Governance and Minimize Political Interference:** Operational independence, along with community involvement, has to be kept as a way of making sure that everything is done fairly and reducing the amount of political power which is not given up.
v. **Leverage Technology:** The introduction of electronic systems to keep track of the use of funds, the progress of projects, and the results of policies should go hand in hand with the setting up of online complaint channels for the quick clearing up of administrative problems.

10. CONCLUSION

The study concludes that institutional and administrative impediments significantly affect the implementation of government policies by cooperative societies in Kollam district. Administrative inefficiencies, weak governance structures, political interference, and lack of managerial competence are major barriers to effective policy execution. Strengthening institutional frameworks, improving administrative efficiency, enhancing managerial skills, and minimizing political intervention are essential to ensure that cooperative societies function as effective intermediaries between the government and the community. Addressing these challenges will not only improve policy implementation but also foster inclusive socio-economic development and strengthen public trust in cooperative governance.

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DISRUPTIVE INNOVATION IN ENGLISH LANGUAGE TEACHING: NAVIGATING DIGITAL INTEGRATION IN THE POST-PANDEMIC ERA

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ABSTRACT: ***The education sector has witnessed technological changes over the years; however, the COVID pandemic necessitated a need for disruptive innovation in education. Disruptive innovation is a term coined by Clayton Christensen. Christensen introduced disruptive innovation to describe how new solutions often begin by serving overlooked or less demanding users before gradually evolving to challenge dominant providers, a pattern increasingly visible in educational technologies. In education, technological advancements are opportunities for disruptive innovations such as Learning Management Systems. Not long ago AI was merely an imaginative concept. Now, it has become widespread in education nearly eliminating paper assignments, blackboard teaching, lectures- that were once synonymous with education. By integrating social media into Virtual Learning Environments, teachers and students could find new imagination and creativity while promoting critical thinking and problem-solving abilities but at the same time ELT has definitely been impacted negatively too. This paper argues how benefits of digital technology in ELT far outweigh the risks.***

KEYWORDS: ***Disruptive Innovation, English Language Teaching (ELT), Digital Integration, Blended Learning, Post-Pandemic Education, Technology***

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1. INTRODUCTION

During the COVID-19 crisis, ELT systems worldwide were compelled to abandon traditional classroom delivery and adopt provisional online formats, accelerating digital practices that had previously evolved more gradually. English Language Teaching (ELT), a field historically reliant on interpersonal classroom interaction and communicative practice, experienced sudden shifts as programs moved online and institutions experimented with blended and hybrid models (Gultom 2023). From an ELT perspective, the post-pandemic era represents a turning point in which disruptive innovation frameworks can illuminate how digital tools, platforms, and pedagogies reshape ELT practices and professional identities. Drawing on disruptive innovation theory and recent empirical and review studies of online, blended, and technology-enhanced language learning, this paper synthesizes evidence about affordances and constraints of digital integration, identifies emergent models like MOOCs, adaptive learning systems, AI-mediated tutoring, flipped classrooms etc and examines equity, teacher roles and the credibility of assessment methods. While this sudden digitization was often described as "emergency remote teaching," the consequential changes persisted beyond immediate crisis responses: many institutions retained and refined online components, teachers developed digital literacies, and learners became accustomed to remote modalities (Simonova 2023).

Originally formulated in business contexts disruptive innovation describes how novel, often lower-cost or more accessible technologies initially target underserved market segments and then move upmarket to challenge incumbents. Applied to education, disruptive innovation clarifies why certain digital solutions (e.g., adaptive learning platforms, low-cost online courses, AI tutors) can reconfigure access, pedagogy, and credentialing—sometimes complementing and sometimes displacing legacy practices.

2. ELT'S DIGITAL INTEGRATION

The need has arisen to synthesize the literature on ELT's digital integration, and assess where disruption is occurring, where sustaining innovation prevails, and propose strategies for navigating this terrain to promote pedagogical quality, equity, and institutional resilience.

Disruptive innovation originally described patterns observed in industries such as disk drives, where entrants introduced products with different performance attributes that appealed initially to non-consumption or low-end users and later encroached upon mainstream markets (Christensen 1997). Later scholarship has refined the construct—distinguishing disruptive from sustaining innovation, emphasizing business models, and recognizing contextual contingencies. In education, "disruption" often occurs when technologies or new delivery models increase accessibility especially to distant learners, working adults; reduce unit costs, or alter credentialing and value propositions. Technologies that enable personalization, automated feedback, and asynchronous practice like adaptive algorithms, automated speech recognition etc, create new teaching and learning possibilities, but they may also reconfigure teacher labour and assessment.

Applying this lens to ELT helps explain why certain digital interventions: adaptive courseware, AI tutors, and mass online courses, have accelerated uptake and why a hybrid ecosystem of classroom teachers, online platforms, and learners is likely to persist (Meng 2023). The pandemic forced near-universal adoption of remote instruction in ELT. Systematic reviews covering 2020–2022 report rapid teacher learning, a proliferation of synchronous video instruction, widespread use of learning management systems (LMS), and innovation in asynchronous resources (Gultom 2023). However, reviews also highlight heterogeneity: access disparities, variable teacher training, and mixed learning outcomes depending on course design and student readiness. As restrictions eased, many contexts moved to blended learning and flipped classrooms combining face-to-face interaction with digitally enriched activities. Empirical studies suggest blended formats often seem to outperform either fully remote or purely face-to-face approaches for communicative competence when well designed. Blended approaches help in retaining the social affordances of physical classrooms while leveraging digital

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tools for personalization, automated assessment, and extended practice. The integration of digital technology and social media into Virtual Learning Environments (VLEs) helped in transforming English Language Teaching (ELT) into a more interactive, creative, and learner-centered experience. By leveraging the connectivity and participatory culture of digital media, teachers and students are no longer confined to the static boundaries of textbooks or classrooms. Platforms such as YouTube, Instagram, X (formerly Twitter), and TikTok provide spaces where learners can produce, share, and comment on authentic language content, thereby enhancing engagement and fostering creativity. When embedded within structured VLEs like Moodle, Google Classroom, or Microsoft Teams, these platforms facilitate collaborative learning communities that extend beyond the classroom, offering continual opportunities for exposure, feedback, and authentic communication.

3. POST PANDEMIC ELT TECHNOLOGIES

A set of technologies using AI which have been particularly salient in post-pandemic ELT are categorized as follows:

(i) Intelligent Tutoring Systems (ITS): AI-powered tutoring systems act as personalized language coaches, adapting to each learner's level, pace, and style. Learners get one-on-one style instruction, real-time correction, and continuous motivation.Examples: Duolingo, ELSA Speak, and Babbel.

(ii) Automated Writing Evaluation (AWE): AI tools assess written work for grammar, coherence, and organization and encourage self-editing skills and helps teachers save time on correction.Examples: Grammarly, ProWritingAid, Quillbot, Criterion.

(iii) Speech Recognition and Pronunciation Training:AI helps learners improve pronunciation and oral fluency using speech recognition. It enhances confidence and speaking proficiency, especially for shy learners. Examples: ELSA Speak, Google Speech-to-Text, Rosetta stone.

(iv) Chatbots and Virtual Language Partners:AI chatbots simulate real-life conversations to improve communication skills and provides low-pressure speaking opportunities and promotes conversational fluency.Examples: ChatGPT, Replika, Mondly Chatbot.

(v) Adaptive Learning Platforms:These systems use AI to track learner progress and adjust instruction dynamically. It enables differentiated instruction for mixed-ability classrooms. Examples: Coursera, Edmodo, Google Classroom with AI integrations.

(vi) Automated Assessment and Feedback Systems:AI assists in grading and evaluating tests, particularly objective and short-answer tasks. It reduces teacher workload and promotes transparency in evaluation.Examples: Turnitin (AI writing detection), ETS e-rater, Cambridge Write & Improve.

(vii) Content Creation and Curriculum Design:AI helps teachers generate lesson plans, quizzes, reading texts, and multimedia materials. Examples: ChatGPT, Canva Magic Write, Quizizz AI, Nearpod.

(viii) Virtual Reality (VR) and Augmented Reality (AR) in ELT: AI integrates with VR/AR to create immersive language experiences. Examples: Mondly VR, ImmerseMe, Google Expeditions.

(ix) AI-Powered Translation and Interpretation Tools:AI improves multilingual communication and comprehension. Examples: Google Translate, DeepL, Microsoft Translator.

(x) Emotional and Motivational Support:AI systems increasingly provide affective support to enhance motivation and engagement. Examples: Replika, chat-based mentoring systems.

(xi) AI in Research and Teacher Professional Development: AI assists teachers and researchers in data analysis, language corpora study, and academic writing. Examples: ChatGPT, Sketch Engine, AntConc.

(xii) Gamification and Adaptive Testing: AI enhances game-based learning and adaptive tests for ELT. Examples: Kahoot AI quizzes, Duolingo adaptive tests, TOEFL AI scoring.

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These affordances support scalable personalization—a hallmark of disruptive offerings with lower per-unit costs while still delivering pedagogically meaningful. A primary benefit of digital integration is the stimulation of imagination and creative expression. Social media and digital storytelling tools allow students to become content creators rather than passive consumers of information. Creating podcasts, digital stories, or short videos in English promotes active language production and situational learning—students experiment with vocabulary, pronunciation, tone, and multimodal expression (Reinhardt 2019). Such activities encourage risk-taking and innovation in language use, elements often constrained in traditional classroom contexts. Teachers can curate project-based tasks that blend linguistic objectives with digital literacy goals, enabling learners to apply English in real-world communicative contexts, which deepen both competence and confidence.

4. BENEFITS OF DIGITAL INTEGRATION

Another major advantage lies in the promotion of critical thinking and problem-solving abilities. Navigating digital media environments requires students to evaluate sources, interpret multimodal information, and negotiate meaning in dynamic online interactions. These processes inherently cultivate higher-order cognitive skills (Bloom, 1956). For instance, when analyzing discourse on social networks or participating in online debates, learners must discern bias, synthesize perspectives, and articulate reasoned responses in English. The interactivity of digital tools thus nurtures reflective and critical engagement rather than rote learning.

The personalization and accessibility afforded by digital technologies also outweigh their risks. Adaptive learning systems and language apps provide individualized feedback and self-paced progression, accommodating diverse learning styles and proficiency levels. For many learners in remote or resource-limited areas, online ELT platforms provide access to qualified instruction and authentic linguistic materials that would otherwise be unavailable .In this sense, digital technology democratizes English education, bridging gaps in opportunity and expanding global participation in language learning.

The significant fact to be noted here is that the benefits of digital integration are uneven. While the disruptive frame highlights opportunity, it also foregrounds risks. Studies repeatedly identify disparities in device access, stable internet, and conducive learning environments—conditions that intersect with socioeconomic status and geography (British Council 2022). While digital models can expand access overall, they risk amplifying inequities if institutions fail to provide infrastructure, training, and inclusive design. Instead of rendering educators redundant, digital systems increasingly reposition teachers as teach designers, facilitators of interaction, and providers of nuanced formative feedback. However, teacher workload and digital skill gaps have been persistent issues; professional development that addresses pedagogical design for blended contexts is crucial in this aspect (Minadzi 2024). Remote and digital assessments accelerated during the pandemic, prompting innovations in automated scoring and remote proctoring. This raises questions about credibility, alignment, and comparability with traditional credentials. These credentialing changes embody disruptive potential by decoupling learning evidence from conventional degree structures. Not all digital content is pedagogically robust. Poorly designed automated tasks or one-size-fits-all modules can generate limited gains, and reliance on technology without sound pedagogical frameworks risks superficial engagement (Soon & Aziz 2022). AI-driven tutors and adaptive platforms offer personalized learning at scale—transforming unit economics and potentially displacing some traditional grammar/skills practice activities. When bundled with low subscription fees, these can erode portions of the mainstream market. Some institutions are repurposing physical spaces for intensive communicative practice while migrating lectures, grammar instruction, or content delivery online—shifting cost structures and pedagogical emphasis (Simonova 2023). Empirical evidence indicates that blended models and adaptive tools can produce positive learning gains when pedagogically integrated. However, the pace and extent of displacement of incumbent institutions varies by context: elite

language programs with reputational capital may sustain demand for in-person offerings, whereas lower-cost segments are more susceptible to disruption. The problem of data privacy and ethics is another issue. Digital platforms collect large amounts of learner data. Questions about consent, privacy protections, and ethical use of learner analytics are pressing—especially when third-party platforms operate across jurisdictions with differing regulations.

To navigate the disruptive dynamics while safeguarding quality and equity, ELT stakeholders can adopt a portfolio of strategies. Adoption decisions should prioritize alignment with communicative objectives—e.g., integrating ASR for deliberate pronunciation practice or adaptive grammar modules as supplementary microlearning—rather than technology for its own sake. Teacher training must focus on instructional design for blended learning and on interpreting learner analytics for formative feedback (Minadzi 2024). Design assessment systems that combine automated formative tools with performance-based summative assessments conducted in moderated, authentic contexts. When issuing micro credentials provide clear mapping to competency frameworks and ensure third-party endorsements or institutional validation to preserve credibility. Policy makers must balance innovation and protection. Key recommendations include establishing quality frameworks for micro credentials and digital courses that include competence mapping, external moderation, and transparent assessment standards, supporting professional development grants and institutional incentives for blended course redesign and teacher upskilling and creating data governance policies that mandate privacy protections, transparency of algorithms, and rights for learners regarding their data. International and national bodies should also promote cross-institutional sharing of best practices, open educational resources (OER), and interoperable credential standards to support mobility and recognition.

5. CONCLUSION

The post-pandemic era has accelerated digital integration in English Language Teaching, creating conditions ripe for both sustaining and disruptive innovation. Disruptive innovation theory helps explain why low-cost, scalable, and personalized digital offerings attract under-served learners and how they may reshape ELT value networks. Yet disruption is not predetermined; institutions, educators, and policymakers have agency to channel innovation toward equitable and pedagogically sound outcomes. Social media and VLE integration thus represent not a threat to traditional language teaching, but a powerful catalyst for its evolution—fostering learners who are linguistically proficient, digitally competent, and critically aware global communicators.AI in ELT is multifaceted—it teaches, evaluates, motivates, personalizes, and innovates. From intelligent feedback systems to immersive VR simulations, AI is not replacing teachers but augmenting their capabilities, enabling more dynamic, inclusive, and learner-centred classrooms. *In post-pandemic language education contexts, by* embracing pedagogically grounded technologies, investing in equitable access, rethinking assessment and credentialing, and supporting teacher professional development, ELT stakeholders can harness digital disruption to expand access, personalize learning, and build resilience—without sacrificing quality or inclusion.

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REVIVING INDIGENOUS FOOD SYSTEMS: A STUDY OF MILLET CULTIVATION IN ATTAPPADY, KERALA

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ABSTRACT:

Objectie: *The primary objective of this research is to examine the revival of millet cultivation in Attappady, a tribal-dominated region of Kerala, by analysing its ecological relevance, socio-economic significance, and contribution to food and nutrition security. The novelty of this paper lies in its interdisciplinary approach that situates millet revival within the broader frameworks of indigenous knowledge systems, climate resilience, food sovereignty, and state-led development interventions. Unlike earlier studies that treat millet cultivation largely as an agronomic or nutritional issue, this research conceptualises it as a socio-political process embedded in questions of marginalisation, governance, and inclusive development.*

Existing Knowledge and Research Gap: *Previous research has established that millets are climate-resilient crops with high nutritional value and that their decline in India resulted from policy neglect, market marginalisation, and the dominance of rice- and wheat-centric food systems. Studies on Attappady have documented persistent malnutrition, livelihood insecurity, and ecological vulnerability among tribal communities. However, limited scholarly attention has been given to understanding how millet revival initiatives interact with indigenous agricultural practices, institutional governance, and evolving market structures. This study addresses that gap by offering a region-specific and policy-oriented analysis.*

Rationale and Significance of the Study: *Recurring episodes of malnutrition and agrarian distress in Attappady demonstrate that food insecurity is not merely a problem of food availability but of access to culturally appropriate, nutritious, and sustainable food systems. Examining millet cultivation is therefore crucial for understanding climate adaptation strategies, tribal livelihoods, and nutrition-sensitive development policies in ecologically fragile regions.*

Parameters and Methodology *The study analyses ecological suitability, production constraints, labour dynamics, seed systems, market access, institutional interventions, and gender roles in millet cultivation. A qualitative methodology based on secondary data analysis is employed, drawing on academic literature, government policy documents, programme reports, and empirical studies.*

Outcomes: *The findings provide policy-relevant insights for strengthening millet-based livelihoods through community institutions, value addition, institutional procurement, and participatory research. The paper concludes that millet cultivation can function as a powerful instrument of food sovereignty, climate resilience, and inclusive development if supported by coordinated institutional mechanisms.*

KEYWORDS: *Millets; Attappady; Tribal Agriculture; Food and Nutrition Security; Climate-Resilient Farming; Indigenous Knowledge; Food Sovereignty*

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1. INTRODUCTION

Attappady, a tribal-dominated taluk located in the Palakkad district of Kerala, occupies a distinctive position in the agrarian, ecological, and developmental landscape of South India. Nestled along the Western Ghats, the region is characterised by undulating terrain, fragile ecosystems, erratic rainfall, and a high dependence on rainfed agriculture. The socio-economic fabric of Attappady is shaped by indigenous communities such as the Irulas, Mudugas, and Kurumbas, whose livelihoods have historically been rooted in subsistence farming, forest-based resources, and collective social institutions.

For generations, millet cultivation formed the cornerstone of food security, nutrition, and cultural identity in Attappady. Crops such as finger millet (ragi), little millet, foxtail millet, barnyard millet, and sorghum were cultivated using indigenous knowledge systems that prioritised mixed cropping, seed preservation, organic inputs, and minimal dependence on external markets. These farming systems were ecologically sustainable and socially embedded, ensuring dietary diversity, risk reduction, and resilience against climatic variability.

The post-independence period, however, marked a decisive shift in India's agricultural and food policies. The Green Revolution prioritised high-yielding varieties of rice and wheat, supported by irrigation, chemical inputs, and price incentives. Rainfed and tribal regions such as Attappady remained outside the ambit of these policies. Over time, subsidised rice distributed through the Public Distribution System replaced millets in household consumption, leading to the erosion of local food systems. This dietary transition weakened nutritional outcomes, reduced agrobiodiversity, and undermined the socio-cultural foundations of tribal agriculture.

In recent years, growing concerns over climate change, malnutrition, and the unsustainability of industrial agriculture have renewed interest in millets at national and global levels. Declared as "nutri-cereals" and promoted through initiatives such as the International Year of Millets, these crops have been repositioned as solutions to contemporary development challenges. In Attappady, state-led programmes such as the Millet Village Programme have sought to revive millet cultivation by integrating indigenous practices with institutional support. Despite these efforts, millet-based agriculture continues to face structural constraints related to production, markets, and governance. This paper critically examines these dynamics to assess the prospects and limitations of millet revival in Attappady.

2. REVIEW OF LITERATURE

The literature on millets broadly emphasises their ecological resilience, nutritional richness, and suitability for marginal environments. The Food and Agriculture Organization (FAO, 2023) identifies millets as key components of sustainable food systems due to their low water requirements, adaptability to climate stress, and contribution to dietary diversity. Scholars argue that millets are particularly relevant for addressing the dual challenges of climate change and malnutrition in developing countries.

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Research on tribal agriculture in India highlights how indigenous food systems were gradually undermined by state policies, market integration, and cultural shifts. India Water Portal (2023) documents how the replacement of millets by subsidised rice altered dietary patterns and eroded food sovereignty in tribal regions, including Attappady. Studies also point to land alienation, forest restrictions, and the expansion of wage labour as factors contributing to the decline of traditional farming practices.

Recent scholarship has focused on millet revival initiatives in Kerala, particularly in Attappady. Herald Open Access (2022) reports positive outcomes of the Millet Village Programme in terms of food security, employment generation, and women's participation. Soumya (2025) emphasises the importance of indigenous knowledge in sustaining millet cultivation and calls for participatory approaches that integrate traditional practices with scientific research.

However, existing studies often treat millet revival as a technical or nutritional intervention, paying limited attention to broader political-economic dimensions such as market access, institutional coordination, and livelihood sustainability. There is a paucity of research that examines millet cultivation through the lenses of governance, gender, and food sovereignty. This study seeks to bridge these gaps by adopting an interdisciplinary and policy-oriented perspective.

3. Objectives Of The Present Research

The present study is guided by the following objectives:

- To analyse the ecological, cultural, and nutritional relevance of millet cultivation in Attappady
- To examine the historical and policy-driven factors contributing to the decline of millet-based food systems
- To assess recent state-led initiatives aimed at reviving millet cultivation among tribal communities
- To identify production, marketing, and institutional challenges faced by millet farmers
- To explore opportunities for sustaining millet-based livelihoods through value addition, institutional procurement, and participatory governance

4. Research Methodology

The study adopts a qualitative research design based on secondary data analysis. Data sources include peer-reviewed academic journals, government policy documents, programme implementation reports, and credible digital repositories related to agriculture, tribal development, and food security. Content analysis is used to synthesise findings across ecological, economic, and institutional dimensions.

This methodological approach is appropriate for capturing the complex interactions between indigenous knowledge systems, policy interventions, and market forces in a geographically and socially marginalised region. While the absence of primary field data is a limitation, triangulation of multiple secondary sources enhances the analytical depth and reliability of the findings.

5. Results Analysis and Interpretation

The analysis reveals that the revival of millet cultivation in Attappady has contributed positively to household food security and dietary diversity. Reintroducing millets into local diets has reduced dependence on nutritionally inferior staples and improved micronutrient intake, particularly among women and children. Millets have emerged as culturally acceptable and nutritionally superior alternatives that align with traditional food habits.

From a livelihood perspective, millet cultivation provides subsistence security and limited marketable surplus. Women play a central role in seed management, post-harvest processing, and food preparation. Women-led collectives, particularly those associated with Kudumbashree, have emerged as key actors

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in processing millets into flour, ready-to-cook mixes, and value-added products. These initiatives have strengthened women's agency and contributed to supplementary household income.

However, production remains constrained by multiple factors. Agriculture in Attappady is highly dependent on monsoon rainfall, making it vulnerable to climatic variability. Erratic rainfall patterns, delayed monsoons, and prolonged dry spells disrupt sowing schedules and reduce yields. Although millets are more resilient than many other crops, extreme weather events increasingly undermine production stability.

Labour shortages constitute another major constraint. Traditional millet cultivation is labour-intensive, involving manual sowing, weeding, harvesting, and processing. Out-migration of younger generations in search of wage employment has intensified labour scarcity, while rising wage rates increase production costs. These factors collectively reduce the economic attractiveness of millet cultivation.

6. Findings

The findings indicate that millet cultivation in Attappady is ecologically viable and culturally significant but economically fragile. While state-led initiatives have improved visibility and institutional support, the absence of assured procurement and stable markets undermines farmer confidence. Market access remains fragmented, with farmers often dependent on intermediaries and receiving a small share of final consumer prices.

Post-harvest processing and storage infrastructure remain inadequate, leading to losses and reduced value realisation. Institutional coordination among agriculture, tribal welfare, women's development, and food supply departments is weak, resulting in fragmented implementation. Delays in subsidy disbursement and procurement payments further discourage farmer participation.

Despite these challenges, significant opportunities exist. Growing urban demand for health foods, integration of millets into public nutrition programmes, and participatory research initiatives offer pathways for strengthening millet-based livelihoods. Linking millet revival with food sovereignty and rights-based development frameworks can enhance both economic and social outcomes.

7. Limitations Of The Present Research

The study relies exclusively on secondary data and does not include primary household-level surveys. As a result, micro-level income impacts, yield variations, and consumption changes could not be empirically measured. Future research incorporating fieldwork and quantitative analysis would provide deeper insights into the livelihood impacts of millet revival.

8. Conclusion

Millet cultivation in Attappady represents a convergence of indigenous knowledge, ecological sustainability, and development policy. While revival initiatives have generated positive outcomes in nutrition, livelihood diversification, and cultural renewal, sustaining these gains requires integrated interventions. Strengthening community institutions, ensuring secure land rights, improving value chains, and aligning agricultural policy with nutrition-sensitive and rights-based governance are essential. With sustained institutional support and ethical market integration, millets can function not merely as crops but as instruments of food sovereignty, climate resilience, and inclusive development in tribal regions such as Attappady.

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TEXT TO FACE IMAGE SYNTHESIS USING GANS AND EMOTION-AWARE LATENT FEATURE EMBEDDING TECHNIQUES

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ABSTRACT:
Human faces convey rich information related to identity, emotion, and intent, making face synthesis an important problem in generative artificial intelligence. While Generative Adversarial Networks (GANs) have shown remarkable success in realistic face generation, synthesizing facial images directly from natural language descriptions remains challenging due to the semantic gap between text and visual features. This paper presents a Text-to-Face Image Synthesis framework using GANs integrated with Emotion-Aware Latent Feature Embedding techniques. The proposed model jointly learns textual semantics and emotional cues by combining transformer-based text encoders with emotion embeddings derived from affective datasets. These fused representations guide a conditional GAN to generate visually realistic and emotionally consistent facial images. Experimental results demonstrate improved semantic alignment, emotional accuracy, and visual quality when compared with conventional text-to-image synthesis models. The proposed approach highlights the importance of emotion-aware latent representations in multimodal generative systems and shows potential for applications in virtual avatars, interactive media, and emotion-driven human–computer interaction.

KEYWORDS: ***GANs, Text-to-Face Synthesis, Emotion-Aware Embedding, Conditional GAN, Facial Expression Generation, Multimodal Learning***

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1. INTRODUCTION

The integration of Natural Language Processing (NLP) and Computer Vision has led to significant progress in generative artificial intelligence. Among various generative tasks, text-to-image synthesis has attracted considerable attention due to its ability to convert descriptive language into visual content. However, generating realistic human faces from text remains a complex challenge because facial images demand high structural precision, emotional accuracy, and identity consistency.

Human faces play a crucial role in communication, conveying age, gender, personality, and emotional states. Small variations in textual descriptions—such as changes in emotional words—can result in significantly different facial expressions. Existing text-to-face synthesis approaches often focus on physical attributes while failing to capture emotional semantics effectively, leading to visually plausible but emotionally neutral outputs.

To overcome this limitation, this study proposes a Text-to-Face Image Synthesis framework using GANs with Emotion-Aware Latent Feature Embedding. The framework explicitly integrates emotional information into the latent space, enabling the generator to produce faces that are both semantically accurate and emotionally expressive.

The proposed approach has applications in virtual avatar creation, digital entertainment, emotion-aware interfaces, forensic visualization, and intelligent content generation. By incorporating emotion into the generative pipeline, the system moves toward more human-centric and expressive AI models.

2. RELATED WORK

Generative Adversarial Networks, introduced by Goodfellow et al., laid the foundation for realistic image synthesis. Subsequent models such as DCGAN, StyleGAN, and Conditional GANs improved visual fidelity and attribute control in face generation.

Early text-to-image models, including GAN-INT-CLS and StackGAN, demonstrated the feasibility of conditioning image generation on text embeddings. Attention-based approaches such as AttnGAN further improved semantic alignment by linking word-level features to image regions. Despite these advanceMENTS, applying such techniques to human face synthesis still remain challenging due to sensitivity to facial structure and expression.

Recent studies have explored text-to-face generation, focusing on identity preservation and attribute alignment. Models integrating BERT or CLIP embeddings improved semantic consistency but largely treated emotion as an implicit feature. Emotion-specific face synthesis approaches using AffectNet or FER2013 datasets achieved controlled expression generation but relied on predefined labels rather than free-form text.

Although diffusion-based models have shown impressive results in text-to-image synthesis, GAN-based approaches remain advantageous for controlled latent manipulation and emotion embedding. Existing research highlights the need for explicit emotion modeling within the latent space, which motivates the proposed emotion-aware GAN framework.

3. METHODOLOGY

The proposed methodology combines text encoding, emotion embedding, and conditional GAN-based image synthesis into a unified framework.

A. System Architecture

The system consists of three main components:

1. **Text Encoder:** A transformer-based model (BERT or CLIP) extracts semantic features from descriptive text.
2. **Emotion Encoder:** An emotion recognition network trained on AffectNet and FER2013 generates emotion embeddings.

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3. **Conditional GAN:** The generator synthesizes face images conditioned on fused text-emotion latent vectors, while the discriminator evaluates realism and emotional consistency.

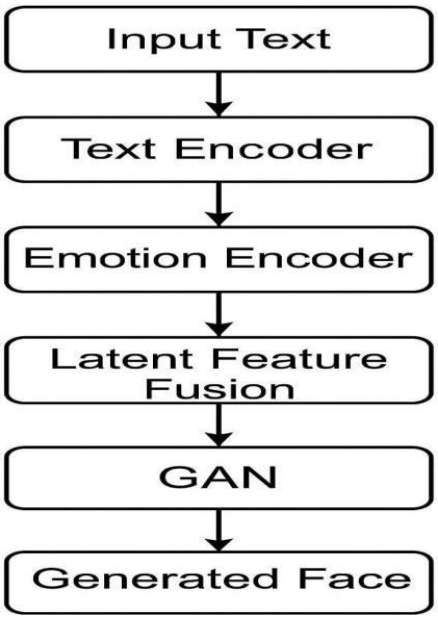

Figure 1: Overall workflow of the text-to-face image synthesis system

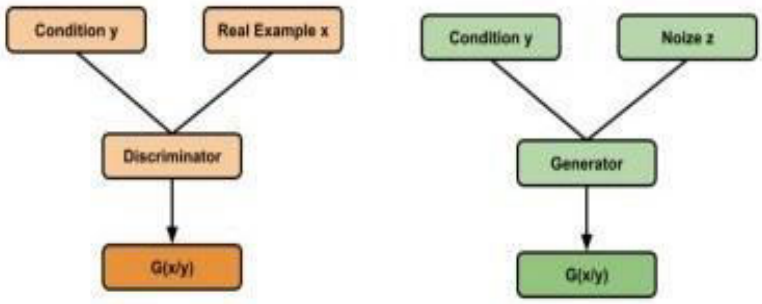

Figure 2: The architecture of the Conditional GAN used in the proposed model

B. Dataset Acquisition

Facial images are collected from publicly available datasets including CelebA, AffectNet, and FER2013. These datasets provide diverse facial attributes and emotion labels. Textual descriptions are created using attribute annotations and emotion tags, forming paired **text–image–emotion triplets** required for supervised training.

C. Dataset Cleaning and Preprocessing

Low-quality, misaligned, and incorrectly labeled images are removed to improve training stability. Face detection and alignment techniques ensure uniform facial positioning. Text data is normalized through tokenization and filtering to maintain linguistic consistency.

D. Data Augmentation

Data augmentation techniques such as flipping, rotation, brightness adjustment, and controlled noise injection are applied to increase visual diversity. Emotion-aware oversampling is used to balance underrepresented emotional categories, improving emotion classification performance.

E. Model Training

Text and emotion embeddings are fused into a shared latent space that conditions the generator. The training process uses adversarial loss for realism, emotion consistency loss for expression accuracy, and feature alignment loss for semantic relevance. Generator and discriminator are trained alternately until convergence.

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4. Model Configuration

The system configuration is summarized as follows:

- **Model:** Conditional GAN with Text and Emotion Encoders
- **Text Embedding Size:** 768
- **Emotion Embedding Size:** 256
- **Latent Vector Dimension:** 100
- **Optimizer:** Adam
- **Batch Size:** 32
- **Training Epochs:** 100–150
- **Evaluation Metrics:** FID, Emotion Classification Accuracy, Cosine Similarity

5. Results And Evaluation

The proposed model achieved strong quantitative and qualitative performance. The system recorded a **Fréchet Inception Distance (FID) of 24.6**, indicating high image realism. Emotion Classification Accuracy reached **91.3%**, confirming effective emotional alignment. Visual inspection showed accurate rendering of facial expressions, hairstyle, and structural attributes corresponding to the input text. Compared to baseline text-to-image GANs, the emotion-aware latent embedding significantly reduced mismatches between facial appearance and emotional intent.

Sample Output

The deployed web-based interface allows users to input natural language descriptions and generate facial images in real time.

Figure 3 shows the system homepage, while

Figure 4, 5, 6 &7 demonstrates real-time visualization of generated faces based on different textual prompts and emotions.

I. SAMPLE OUTPUT

a. Home Page

The project output screenshots are shown as follows:

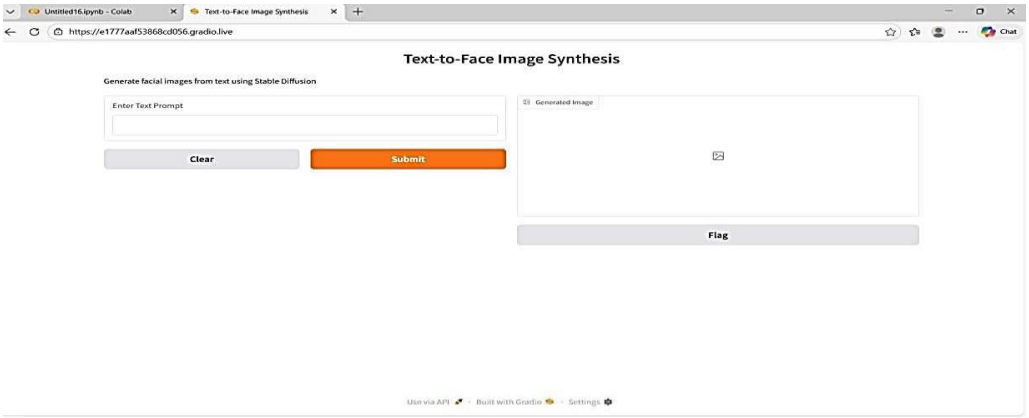

Figure 3: Home Page

The homepage of the Text-to-Face Image Synthesis system provides a simple, user-friendly, and interactive web-based interface for generating facial images from textual descriptions. The interface is designed to simulate real-time forensic and investigative scenarios, where a witness or user can describe an individual's facial features in natural language. At the top of the homepage, the project title "Text- to-Face Image Synthesis" is clearly displayed, indicating the purpose of the application. Below the title, a text input field labeled "Enter Text Prompt" allows users to input descriptive

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information such as age, hairstyle, facial structure, expression, and clothing. This text prompt acts as the primary input to the deep learning model The homepage includes a Submit button, which triggers the image generation process, and a Clear button to reset the input field for new descriptions. Once the prompt is submitted, the generated facial image is displayed in the designated output area on the right side of the interface. This layout enables users to view results instantly, supporting real-time interaction and analysis. The overall design of the homepage emphasizes simplicity, accessibility, and efficiency, making it suitable for applications such as forensic facial reconstruction, criminal investigation support, and academic research demonstrations. The web interface is implemented using Gradio, allowing seamless deployment with a public URL and enabling easy access across different devices.

b. Real Time Visualization

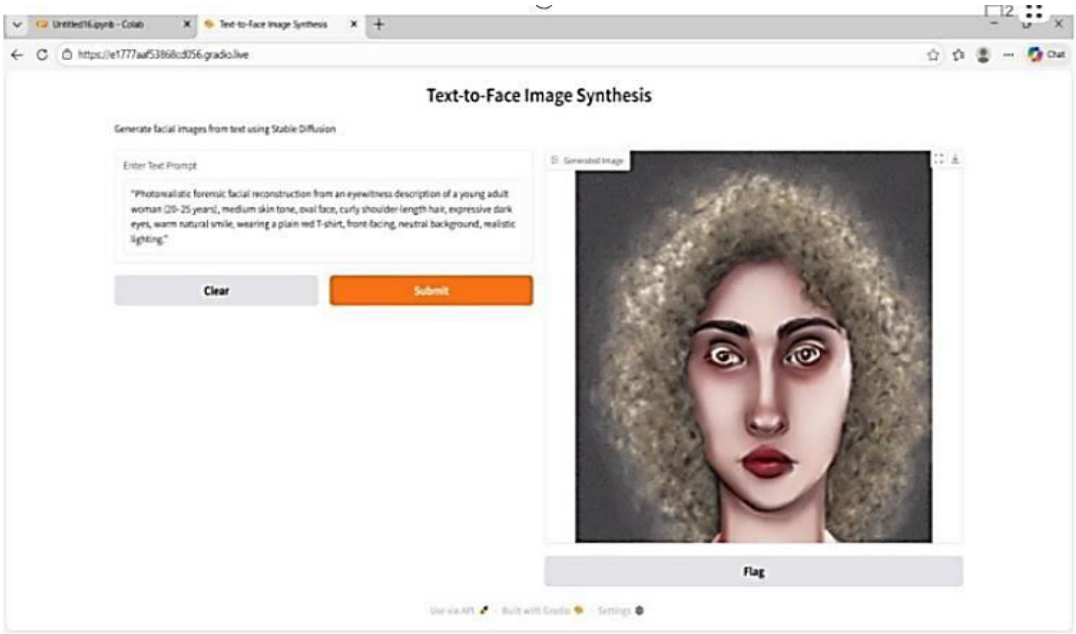
Text-to-Face Image Synthesis
Generate facial images from text using Stable Diffusion
Enter Text Prompt
"Photorealistic forensic facial reconstruction from an eyewitness description of a young adult woman (20-25 years), medium skin tone, oval face, curly shoulder-length hair, expressive dark eyes, warm natural smile, wearing a plain red T-shirt, front-facing, neutral background, realistic lighting."
Clear
Submit
Flag

Figure 4: Real Time Visualization

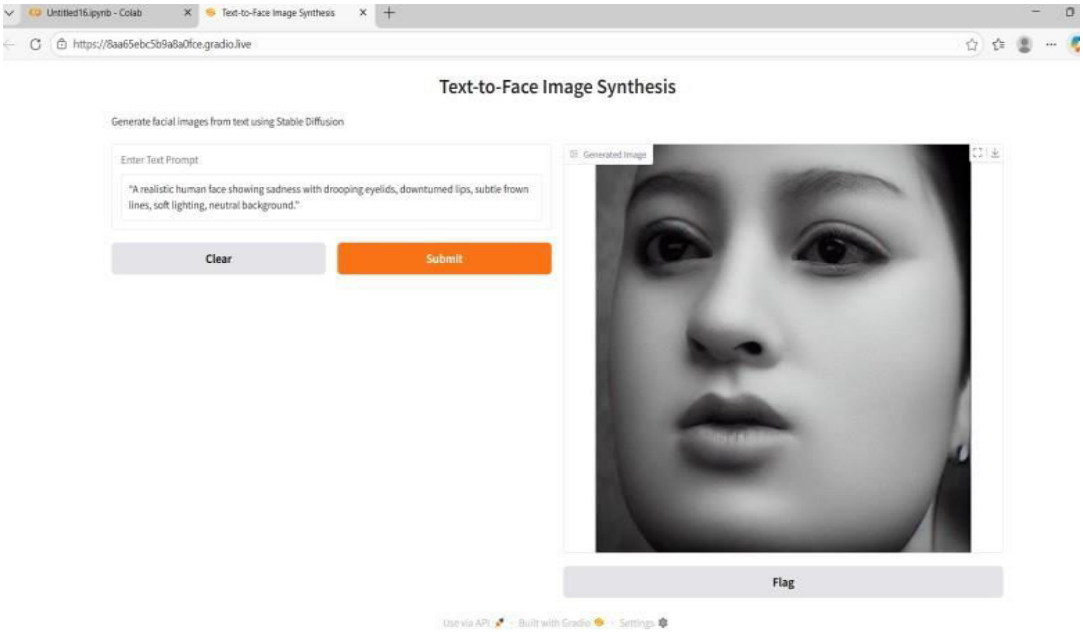
Text-to-Face Image Synthesis
Generate facial images from text using Stable Diffusion
Enter Text Prompt
"A realistic human face showing sadness with drooping eyelids, downturned lips, subtle frown lines, soft lighting, neutral background."
Clear
Submit
Flag

Figure 5: Real Time Visualization

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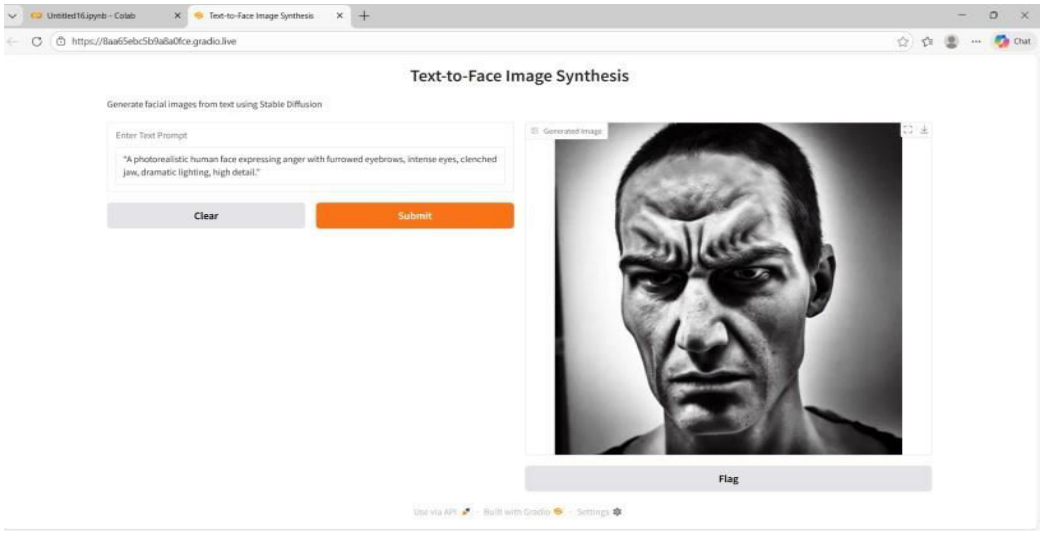
Text-to-Face Image Synthesis
Generate facial images from text using Stable Diffusion
Enter Text Prompt
"A photorealistic human face expressing anger with furrowed eyebrows, intense eyes, clenched jaw, dramatic lighting, high detail."
Clear
Submit
Flag

Figure 6: Real Time Visualization

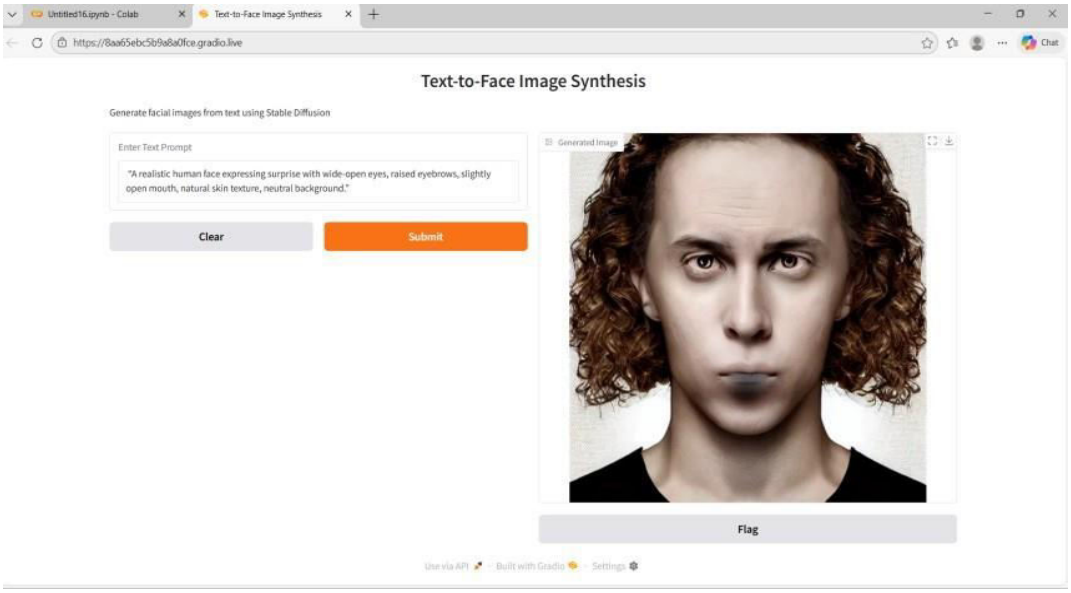
Text-to-Face Image Synthesis
Generate facial images from text using Stable Diffusion
Enter Text Prompt
"A realistic human face expressing surprise with wide-open eyes, raised eyebrows, slightly open mouth, natural skin texture, neutral background."
Clear
Submit
Flag

Figure 7: Real Time Visualization

6. Conclusion And Future Work

This study presented a Text-to-Face Image Synthesis framework using GANs with Emotion-Aware Latent Feature Embedding, capable of generating realistic and emotionally expressive facial images from natural language descriptions. By integrating textual semantics and affective cues into a unified latent space, the system achieved improved visual quality and emotional fidelity.

Future work will focus on expanding emotion-labeled datasets, incorporating diffusion-based generative models, supporting multilingual text input, optimizing real-time performance, and extending the framework to 3D face generation and animation. The proposed approach represents a meaningful step toward emotionally intelligent and human-centered generative AI systems.

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EMOTIONAL INTELLIGENCE AS A DETERMINANT OF LIFE SKILLS AMONG PROSPECTIVE TEACHERS

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ABSTRACT:
Teaching is considered one of the more stressful professions, particularly due to the frequent interpersonal interactions with students and society, where educators must navigate not only the emotions of students, parents, and colleagues, etc. Emotional intelligence (EI) has been recognized as an important concept across various areas of everyday life, such as mental health and physical health, social interactions, academic and workplace performance. In this study, the emotional intelligence of Prospective teachers (B.Ed students) is taken for research. A normative survey method was adopted for this study. The researcher chose 500 students from 10 B.Ed colleges located in Madurai District, Tamil Nadu, India as a sample. This study uses a purposive sampling method. The investigator constructed & validated a tool for the Emotional Intelligence Rating Scale (EIRS). The statistical tools used in this study are frequency analysis and the t-test..

KEYWORDS: ***Emotional Intelligence, Prospective Teachers, Life Skills, Teaching***

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1. INTRODUCTION

Life skills denote the capabilities that allow people to efficiently manage challenges, demands of day to day life. They enhance mental well-being in young people and help them confront real-life situations. Education in life skills fosters mental health and readiness, equipping individuals to act in socially positive ways. Life skills education empowers children, encouraging them to take greater responsibility for their actions. These skills inspire healthy behaviors and boost self-confidence. Consequently, we can assert that they contribute to improved psychological health and play a significant role in preventing psychological disorders and behavioral issues. For instance, research on substance abuse has showed that three interconnected factors are involved: - Low self-worth, challenges in conveying feelings, and insufficient relationship skills.

Despite the technological and educational development, the educational institutes are often challenged by the issues regarding the educational system. These concerns primarily revolve around unsatisfactory academic results, the pressures and expectations placed by parents, the declining standards of education, the inactivity of students, the excessive burdens on teachers, and so on. Such challenges hinder teachers' ability to meet both academic progress and the societal expectations from parents and students. Social pressure builds emotional interactions and challenges among teachers. Ignat and Clipa (2012) believe that if educators emphasize the enhancement of their professional and emotional skills, they can more easily overcome such challenges. In this context, emotional intelligence (EI) acts as an essential resource that assists teachers in managing their emotions when faced with societal issues that disrupt their emotional stability. In addition, the views of Beilock and Ramírez (2011) states that it is important to study the emotions of a classroom environment in order to recall the learning patterns and motivations of the student. The capability to comprehend and oversee the emotions in social contexts is crucial to attain success in interpersonal and career domains (Zeidner, Matthews & Roberts, 2004). Emotional intelligence is a significant psychological element that greatly influences an employee's capabilities and performance.

The famous psychologist E.L. Thorndike gave emphasis on Emotional Intelligence through his concept of social intelligence 1920. Thorndike characterized social intelligence as “the capacity to understand and interact with individuals of various ages and genders in order to enhance social connections.” Goleman stated that “Emotional intelligence accounts for skills that are different from, yet complementary to, academic intelligence, which is linked to cognitive abilities reflected in IQ tests.” It pertains to “the capacity to identify our own thoughts as well as those of others, to gain insight into ourselves, and to regulate our emotions and those of others.” He argues that emotional intelligence constitutes a crucial group of psychological skills associated with life success.

The primary focus of an educational community revolves around the teacher, who serves as a facilitator for interpersonal connections and the educational processes. Consequently, social and emotional skills are acknowledged globally as a fundamental component of a ‘knowledge society’.

2. REVIEW OF LITERATURE

The way individuals manage their emotions and skills affects learning experiences, overall well-being—both psychological and bodily—the quality of relationships, academic success (Brackett & Caruso, 2007). Thus, the emotional intelligence of teachers is essential not only for their own health but also for promoting effective teaching and learning, especially in supporting students' socio-emotional growth (Sutton & Wheatley, 2003).

Positive emotions among teachers can enhance their well-being and lead to a more favorable learning environment (Sutton & Wheatley, 2003). In contrast, negative feelings such as anxiety, depression, and anger can reduce cognitive functioning and information processing capacity (Eysenck & Calvo, 1992). Teaching is inherently a demanding job. An increase in negative stress levels and insufficient emotional intelligence may result in burnout. A study said that burnout negatively impacts teachers’ mental and

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physical health, but also the effectiveness of teaching and learning outcomes. Previous research suggests that negative emotions can affect both trainee performance and the character of educational instruction (Vanderberg & Huberman, 1999).

Emotional intelligence favorably influences a teacher's self-belief. Since teachers' self-belief is connected to pupils' empowerment, improving educators' emotional intelligence seems to be a further effective approach for improving student success. Educators with high emotional intelligence often apply more coping strategies in response to various school-related stressors, leading to greater productivity (Brackett & Palomera). It is commonly noted that educators view emotion management as a crucial skill for achieving academic goals, fostering healthy social connections, and succeeding in educational environments (Sutton & Harper).

The service industry, emotional intelligence is especially vital due to the constant and direct interactions between individuals. A study in the food service industry by Sy, Tram, O'Hara (2006) found that Individuals in leadership positions who possess high emotional intelligence tend to perform better at addressing the needs of their employees in terms of job management within the organization. Similarly, other researchers have explored the link between transformational leadership and their ability to influence the emotions and moods of both customers and employees (Bono, Foldes, Vinson & Muros, 2007). Leaders possessing strong emotional intelligence frequently engage in emotional labor at work to maintain professionalism, thereby creating an appropriate emotional environment during interactions. In this context, emotional labor refers to the management the adjustment of one's emotions to meet job and organizational expectations is an important aspect of workplace dynamics (Diefendorff et al., 2005; Pugh, 2001). Bono and Vey (2007) emphasized the crucial role of emotional labor in job performance, particularly within the service industry. However, Grandey, Fisk, and Steiner (2005) noted that emotional labor can be quite taxing for employees who lack sufficient autonomy in their roles. Despite these challenges, workers can effectively manage and shape their emotions even in difficult situations.

A person's capacity to understand their own emotions helps in regulating those feelings during interactions with others. Additionally, it aids in recognizing when emotional labor is necessary. Brotheridge (2006) argues that emotional intelligence plays an important role in anticipating situational requirements, which can then guide expectations for emotional labor. Employees with high emotional intelligence recognize that expressing emotions is vital for their roles. Furthermore, for jobs that require emotional labor, performance in such roles can be anticipated through the framework of emotional intelligence (Joseph & Newman, 2010).

Tobias et al., 2025, study says that "Exploring Emotional Intelligence and Teaching Performance of New Generation Educators." Emotional intelligence (EI) is crucial for enhancing the performance of new educators, as research links higher EI to better teaching and student outcomes. This study aims to improve professional development and support for future educators.

Maraza-Quispe et al., 2025, this study titled "Emotional Intelligence in Teaching: A Key to Performance and Institutional Climate in Basic Education" explores the connection between emotional intelligence (EI), teaching performance, and institutional climate (IC) within the realm of basic education. The findings indicate that higher levels of emotional intelligence are positively associated with enhanced teaching effectiveness and a more favorable school environment. As a result, the study advocates for the implementation of EI training programs to foster improvements in both teaching quality and institutional climate.

Tolentino, 2023, Study shows that "Emotional Intelligence and Experiences: Their Relationship to Teaching Performance". This study explored the connections between the profiles of teachers, their experience, emotional intelligence, and their effectiveness in teaching. Utilizing Google Forms, it applied a descriptive-correlational approach to assess demographic information. Findings revealed that emotional intelligence and experience significantly enhance teaching performance. The study

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recommends collaboration among district supervisors, principals, and donors to support teachers' postgraduate education.

J.H. West & P. Cougar Hall, 2011,shows that "Potential predictors of student teaching performance: Considering emotional intelligence". The study found a positive link between GPA and Praxis scores with teaching performance in 74 student teachers, accounting for 16% of variance. However, emotional intelligence showed no correlation with teaching performance.

3. OBJECTIVES

- To assess the level of Emotional Intelligence of prospective teachers
- To study the Emotional Intelligence of prospective teachers with respect to their gender
- To research the Emotional Intelligence of prospective teachers with respect to their educational qualification

4. HYPOTHESES

- There will be a significant difference between Men and Women with respect to their Emotional Intelligence among prospective teachers
- There will be a significant difference between Undergraduates (UG'S) and Post graduates (PG'S) with respect to their Emotional Intelligence among prospective teachers

5. METHODOLOGY

In this study, the normative survey method was utilized. The study population consisted of prospective teachers, specifically B.Ed students, enrolled in various colleges of education across Tamil Nadu, India. The researcher selected a sample of 500 B.Ed students from 10 colleges situated in the Madurai District, using a purposive sampling strategy. The goal of this approach was to maintain a balanced representation of male and female participants in the sample. Both genders were included, along with a diverse set of twelve subjects: Tamil, English, Mathematics, Physical Science, Biological Science, History, Geography, Home Science, Commerce, Economics, Computer Science, and Social Science, with their selection reflecting the overall population proportions. The investigator developed and validated an Emotional Intelligence Rating Scale (EIRS) for this study. To analyze the data, frequency analysis and the 't' test were employed as the statistical methods.

6. STATISTICAL ANALYSIS

Table 1: Distribution of Frequencies Regarding Emotional Intelligence Levels

S.No	Level of Emotional Intelligence	Frequency	Percentage
1	Low	134	26.8
2	Mediocre	237	47.4
3	High	129	25.8
Total		500	100

From the table, we can see that 26.8% of students fall into the low level of emotional intelligence, 47.4% are at the mediocre level, and 25.8% qualify as having a high level. As a result, we determine that most students possess a mediocre level of emotional intelligence.

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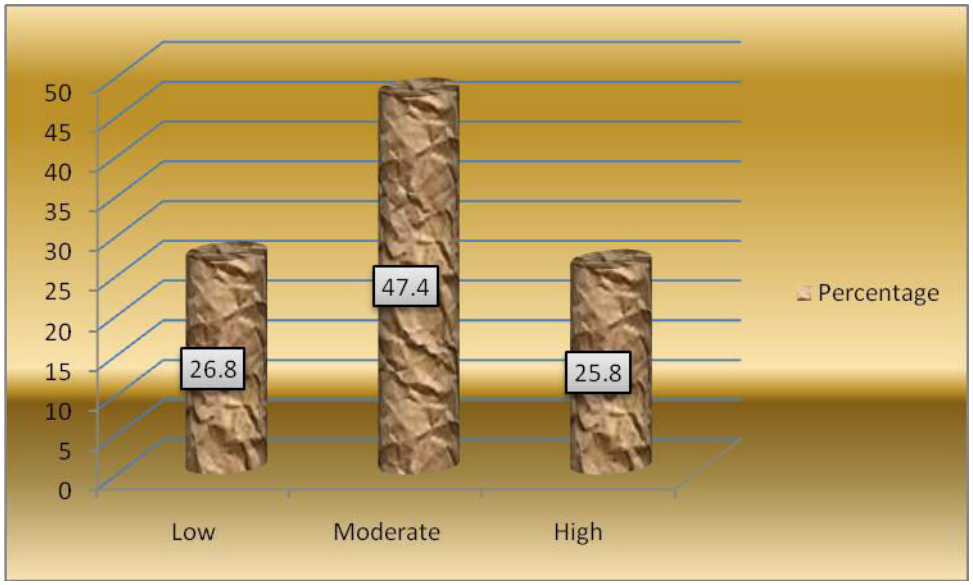

Figure 1: Level of Emotional Intelligence

Hypothesis I

There will be a significant difference between Men and Women with respect to their Emotional Intelligence among prospective teachers

Table 2: 't' values related to differences in gender

Correlates	Gender	N	Mean	Std. Deviation	't' value	Level of Significance
Emotional Intelligence	Men	200	44.51	9.65	1.55	NS
	Women	300	43.16	9.32		

The computed 't' value is 1.55, which is lower than the critical value of 1.96. Since it is not significant, we accept the null hypothesis. Thus, we determine that there is no meaningful difference in emotional intelligence between male and female prospective teachers.

Hypothesis II

There will be a significant difference between Undergraduates (UG'S) and Post graduates (PG'S) with respect to their Emotional Intelligence among prospective teachers.

Table 3: 't' values for Educational Qualification

Correlates	Educational Qualification	N	Mean	Std. Deviation	't' value	Level of Significance
Emotional Intelligence	UG	408	43.72	9.67	0.1	NS
	PG	92	43.62	8.53		

The above table shows that the calculated 't' value is 0.1, which is less than the table value of 1.96, it is not considered significant. Hence, we accept the null hypothesis. This concludes that there is no significant difference in emotional intelligence between undergraduates (UGs) and postgraduates (PGs) among prospective teachers.

7. FINDINGS AND INTERPRETATION

This study indicates that the majority of prospective teachers possess a moderate level of emotional intelligence. It concludes that there is no significant difference in emotional intelligence between men and women among these prospective teachers. This finding is encouraging since it suggests that gender does not affect emotional intelligence in this group. Additionally, the study found no significant

difference in emotional intelligence between undergraduates (UGs) and postgraduates (PGs) among prospective teachers, which implies that educational qualification does not influence emotional intelligence either. Overall, these findings are fairly positive.

8. CONCLUSION

Today's educators are required to exhibit strong intellectual, ethical, and social growth while encouraging these traits in their students. They must learn to work collaboratively with the entire educational community, comprehend their surroundings, and run schools efficiently. The demanding role of educators in the constantly evolving landscape of Indian society underscores the necessity for reform in pre-service teacher training programs. Emotional Quotient (E.Q.), which gauges emotional intelligence, is as critical—if not more so—than Intelligence Quotient (I.Q.), which assesses abstract reasoning to achieve success and fulfillment in life, it is essential to have educators who are proficient in imparting life skills. Only those teachers equipped with these vital competencies can effectively prepare individuals for the challenges they may encounter and can impart these vital abilities to their students at the same time. This means that teacher education programs should encompass thorough training in life skills. For existing teachers, regular in-service training on life skills should be organized by university education departments, colleges for teacher training, and teacher education universities. This strategy will ultimately strengthen the student community.

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ESG PERFORMANCE IN INDIAN INDUSTRIES: A FIVE-YEAR SECTORAL ANALYSIS (2020-2024)

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ABSTRACT:

Environmental, Social, and Governance (ESG) performance has developed as a critical benchmark for evaluating a company's commitment to sustainable and ethical practices. ESG performance reflects how effectively organizations manage environmental risks, promote social responsibility, and uphold strong governance structures. This abstract looks into how ESG metrics are becoming crucial in defining corporate strategies, believable investor choices, and ensuring adherence to regulations. With global and domestic stakeholders increasingly demanding transparency and accountability, companies that determine strong ESG performance are more possible to gain competitive advantages, reduce risk exposure, and build long-term value. The study of ESG performance also discloses significant transformations across industries and geographies, highlighting the need for standardized frameworks and greater integration of ESG factors into financial and operational decision-making. As ESG continues to evolve from a voluntary initiative to a strategic imperative, understanding its impact is essential for sustainable economic development and responsible business growth.

KEYWORDS: ***ESG criteria, ESG performance, Sectoral Performance, significant transformations***

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1. INTRODUCTION

Environmental, Social, and Governance (ESG) refers to the three key factors used to evaluate the sustainability and ethical impact of an investment in a company or business. As global awareness of climate change, social justice, and corporate transparency increases, ESG has become a crucial framework for businesses and investors. Environmental, Social, and Governance (ESG) performance has gained significant traction in India over the past decade, reflecting a global shift toward sustainable and responsible business practices. With increasing pressure from investors, regulators, and consumers, Indian companies are recognizing the importance of integrating ESG principles into their core strategies. The Securities and Exchange Board of India (SEBI) has been instrumental in pushing ESG disclosures through the Business Responsibility and Sustainability Reporting (BRSR) framework, making sustainability reporting mandatory for the top listed companies. While ESG adoption in India is still evolving, there is a growing emphasis on environmental sustainability, social equity, and corporate accountability as drivers of long-term value creation. Sectoral analysis of Environmental, Social, and Governance (ESG) performance in Indian industries reveals significant variations, driven by the inherent nature of their operations, regulatory pressures, investor expectations, and the maturity of their sustainability practices. The last 5 years (2020-2024) have been extremely significant for the adoption and evolution of Environmental, Social, and Governance (ESG) by Indian industry.

2. ESG CRITERIA

ESG criteria are the principles used to evaluate a company's operations and their impact on the world, beyond just financial performance. These criteria help to factor in aspects of investment decisions, specifically environmental, social, and corporate governance factors.

ENVIRONMENTAL	SOCIAL	GOVERNANCE
• Climate Change and Carbon Emissions. • Resource Depletion and Pollution. • Biodiversity and Conservation. • Environmental Compliance.	• Labor Practices • Human Rights • Employee Welfare and Engagement • Community Relations. • Stakeholder Engagement • Product Responsibility and Customer Welfare	• Corporate Governance Structure • Ethics and Business Conduct • Risk Management and Internal Controls • Transparency and Disclosure

3. THE REGULATORY LANDSCAPE: A GAME CHANGER

Section 135 of the Companies Act 2013, which compels particular corporations to allocate a component of profits towards CSR activities. It goes hand-in-hand with 'S' (social) within ESG, as its duty is to promote the social well-being of society. The most significant development impacting ESG performance in India during this period has been the Securities and Exchange Board of India's (SEBI) introduction of the Business Responsibility and Sustainability Reporting (BRSR) framework.

- **Voluntary Disclosure (FY 2021-22):** SEBI initially encouraged voluntary BRSR disclosures for the top 1000 listed companies.
- **Mandatory Disclosure (FY 2022-23 onwards):** BRSR became mandatory for the top 1000 listed companies by market capitalization from FY 2022-23. This replaced the older Business Responsibility Report (BRR) and introduced a more comprehensive and rough reporting format, aligning with international frameworks like Global Reporting Initiatives (GRI) and Task force on climate related Financial Disclosures (TCFD).

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- **BRSR Core (July 2023 onwards):** SEBI further strengthened the framework by introducing "BRSR Core," mandating assured disclosures on key ESG parameters, including value chain reporting (from FY 2025-26, with assurance from FY 2026-27 for specific thresholds). This has significantly enhanced the credibility and comparability of ESG data.

These regulations have not only increased the volume of ESG data but also pushed companies to focus on the quality and robustness of their disclosures, moving beyond mere compliance towards genuine integration.

4. SECTORAL PERFORMANCE: DIVERGENT PATHS

ESG performance refers to how well a company or organization manages its environmental, social, and governance (ESG) practices and impacts. It's a framework used to assess a company's sustainability and ethical behavior, including its impact on the environment, its treatment of people (employees, communities, etc.), and the effectiveness of its governance structures. Based on analyses from various ESG rating agencies (like CRISIL, MSCI, and Refinitiv) and academic studies, a clear pattern of sectoral ESG performance has emerged over the last five years. The provided data seems to be a set of ranges from low to high. Most industries show relatively high average scores, from the mid -60s to the mid -90s. It represents a scoring or grading system with associated performance or risk level.

Table 1: Scoring Pattern Across Different Industries

PARAMETERS	MAX.	AVG.	MED.	MIN.	MAX-MIN Spread	MAX-AVG Spread
Sample	**(82)**	**(70)**	**(70)**	**(57)**	**(25)**	**(13)**
Information Technology	82	75	75	66	16	7
Financial Services	82	73	75	59	23	9
- Banks	82	75	76	63	19	8
- Insurance	77	71	72	59	18	7
- Other Financial Services	79	72	73	63	20	7
Consumer Durables	76	72	73	63	13	4
Fast Moving Consumer Goods	77	70	72	62	15	8
Others	75	70	69	59	16	5
Automobile and Auto Components	77	70	69	63	14	7
Healthcare	76	69	70	64	12	7
Oil Gas & Consumable Fuels	74	68	69	64	10	6
Consumer Services	76	68	70	63	12	7
Power	75	68	67	61	14	7
Construction Materials	74	67	66	61	12	7
Capital Goods	72	67	67	62	10	5
Metals & Mining	70	66	66	57	13	4
Chemicals	72	65	65	59	13	7

Sources: SES REPORT JULY 2024

(i)Leading Sectors:

ESG metrics can be categorized into two primary groups: quantitative and qualitative. Quantitative metrics rely on numerical information that can frequently be measured directly and compared. Instances of quantitative ESG metrics encompass greenhouse gas emissions, energy consumption, staff turnover rates, and documented HR infractions. It similarly offers a method to assess

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business risks and prospects in those sectors. ESG performance across different Indian industrial sectors:

a. Information Technology (IT) & Software:

- **Performance (2020-2024):** Consistently holding its position among the top performers.
- **Drivers:** Low inherent environmental footprint compared to manufacturing. Strong emphasis on human capital (talent retention, diversity & inclusion, and employee well-being) due to the nature of their business. Robust corporate governance practices, often driven by global client demands and international listing requirements.
- **Trends:** Continued focus on greening their operations (e.g., renewable energy for data centers, reducing e-waste), ethical AI, data privacy, and upskilling their workforce.
- **Challenges:** Managing the environmental footprint of their global supply chains and the ethical implications of emerging technologies.

b. Financial Services (Banking, NBFCS, Insurance):

- **Performance (2020-2024):** Show significant improvement and relatively strong overall ESG performance. The banking sector, in particular, has demonstrated notable progress.
- **Drivers:** Increased regulatory scrutiny from RBI and SEBI on sustainable finance, green lending, and risk management related to ESG factors. Growing demand from domestic and international investors for ESG-aligned financial products. Focuses on financial inclusion (social aspect) and robust governance due to the highly regulated nature of the industry.
- **Trends:** Significant growth in green financing, development of ESG-themed financial products, and integrating ESG risk assessments into lending decisions. Private Banks have often shown greater initiative than public sector counterparts.
- **Challenges:** Measuring and managing "financed emissions" (the emissions of their clients) and ensuring fair lending practices across diverse demographics.

c. Fast-Moving Consumer Goods (FMCG):

- **Performance (2020-2024):** Showing steady improvement, particularly on social and environmental fronts visible to consumers.
- **Drivers:** High consumer awareness regarding sustainable products and ethical sourcing. Pressure from stakeholders regarding packaging waste, water usage, and fair labor practices in their supply chains.
- **Trends:** Increased investment in sustainable packaging (e.g., plastics circularity), water stewardship, responsible sourcing of raw materials, and community development initiatives.
- **Challenges:** The vast and complex supply chains make comprehensive ESG oversight difficult. Managing plastic waste and transitioning to truly circular business models remains a significant hurdle.

(ii) Improving But Challenged Sectors: The Manufacturing And Heavy Industries

a. Metals & Mining, Cement, Chemicals, Energy & Power:

- **Performance (2020-2024):** Historically lower ESG scores, especially on environmental parameters, but showing concerted efforts towards improvement.
- **Drivers:** Intense regulatory pressure to reduce emissions and pollution. High capital expenditure essential for de-carbonization technologies. Growing investor demand for transition plans and TCFD-aligned disclosures.
- **Trends:** Significant investments in renewable energy adoption, carbon capture technologies, water recycling, and waste reduction. Increased focus on occupational health and safety (social) due to the inherent risks in these industries. Greater transparency in reporting their environmental impact under BRSR.
- **Challenges:** The inherent nature of these industries means high energy consumption, substantial GHG emissions, and resource intensity. Achieving "Net Zero" targets requires

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massive investments and technological breakthroughs. Balancing economic growth with environmental responsibility remains a core tension.

b. Automotive:

- **Performance (2020-2024):** A sector undergoing a significant transformation towards electric vehicles (EVs) and sustainable manufacturing.
- **Drivers:** Government push for EV adoption (FAME India scheme), rising consumer preference for greener vehicles, and global supply chain pressures for sustainable practices.
- **Trends:** Heavy investment in EV production, battery technology, and charging infrastructure. Focus on reducing emissions from manufacturing plants, responsible sourcing of minerals (e.g., lithium, cobalt), and end-of-life vehicle recycling.
- **Challenges:** Managing the move from Internal Combustion Engines (ICE) to EVs, ensuring ethical sourcing of critical minerals, and building robust charging infrastructure.

c. Poor Sectors:

a. Mining And Metals

- **Performance:** Generally low, with some improvements in larger, listed companies driven by investor pressure and regulatory changes. However, widespread adoption of strong ESG practices across the entire sector, including smaller and informal operations, remains a significant challenge. Environmental liabilities (pollution, land degradation), occupational health and safety failures, and community disruptions are frequently reported issues.
- **Drivers:** Inherently resource-intensive, leading to significant land degradation, water pollution, air emissions (GHG and particulate matter), and biodiversity loss. Decommissioning and rehabilitation of mines are often inadequate.
- **Trends:** While there's increased awareness and some larger companies are making efforts due to investor pressure, the sector as a whole still struggles with established environmental and social issues. Directing push is compelling nearly developments, but performance remains unreliable.
- **Challenges:** Inherently resource-intensive, leading to significant land degradation, water pollution, air emissions (GHG and particulate matter), and biodiversity loss. Decommissioning and rehabilitation of mines are often inadequate. Transparency issues, illegal mining activities, and challenges in regulatory enforcement. Data accessibility for comprehensive ESG reporting is limited. Mines are susceptible to physical climate risks (e.g., floods affecting operations) and face pressure to decarbonize.

d. Textile Manufacturing

- **Performance (2020-2024):** Large recognized companies might show some progress due to export market demands and access to capital. However, the vast majority of MSMEs (which constitute a significant portion of Indian manufacturing) exhibit very low ESG performance. Issues include high energy and water consumption, significant wastewater discharge, hazardous waste generation, and poor labor practices.
- **Drivers:** Initiatives encouraging energy efficiency, cleaner production technologies, and formalization of labor can provide some support, still interest can be slow. Easier access to flexible and affordable clean technologies for energy, water, and waste management. Growing interest from banks and financial institutions in providing to ESG-compliant businesses, creating an incentive.
- **Trends:** Evolution is slow, especially for MSMEs, due to cost suggestions, lack of awareness, and limited regulatory oversight for the huge informal sector.
- **Challenges:** High energy consumption, water pollution (especially from dyeing and chemical units), air emissions, and inadequate waste management. Many units lack emission treatment plants or proper disposal mechanisms. Prevalence of informal labor, low wages, long working

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hours, lack of social security benefits, and inadequate health and safety standards. Child labor remains a concern in some unorganized segments

5. Main Trends And Insights (2020-2024):

(i) **Shift from "tick-box" to integration:**
While compliance with BRSR remains a primary driver, there's a discernible shift, especially among larger companies, towards integrating ESG into business strategy. This has been accelerated by the "leadership indicators" in BRSR, encouraging a more proactive approach.

(ii) **Enhanced data quality and transparency:**
The mandatory nature of BRSR has significantly improved the quality, granularity, and comparability of ESG data offered in the public domain. This permits for more meaningful sectoral analysis and investor decision-making.

(iii) **Growing investor engagement:**
Domestic institutional investors are increasingly incorporating ESG criteria, mirroring global trends. This has put direct pressure on company boards to prioritize ESG.

(iv) **Focus on "s" and "g" for value creation:**
While environmental concerns are critical, many Indian companies initially focused on Governance (due to pre-existing regulations) and Social aspects (often through CSR initiatives). However, the BRSR is pushing for more robust environmental disclosures.

(v) **Challenges persist:**

a. **Data Reliability & Verification:** While improving, ensuring 100% accuracy and third-party assurance for all reported ESG data remains a challenge, mainly for smaller companies and complex value chains.

b. **Lack of Internal Expertise:** Many companies, especially SMEs, still struggle with the technical expertise and resources required for comprehensive ESG data collection, analysis, and reporting.

c. **Greenwashing Risk:** As ESG gains prominence, the risk of companies making unsubstantiated claims or engaging in "greenwashing" persists, necessitating stronger regulatory oversight and independent verification.

d. **Financial Impact Disconnect:** While studies show a positive long-term connection between ESG performance and financial returns, demonstrating a clear, short-term financial benefit can still be elusive for some companies, particularly those in capital-intensive sectors making large upfront investments in sustainability.

6. Conclusion

The years 2020-2024 are a transition period for ESG in Indian businesses. The strong regulatory framework, in particular BRSR, has helped in terms of standardizing ESG disclosures and promoting more meaningful integration. The services are efficiently carrying it out, while heavy industry is having more of a struggle doing it, but increasingly even they are taking initiatives. The next five years will likely see further refinement of reporting standards, increased capital allocation towards sustainable projects, and a stronger linkage between ESG performance and tangible business value across all sectors of the Indian economy.

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INPUT AND OUTPUT ORIENTED EDUCATIONAL EFFICIENCY: A STATE LEVEL STUDY BASED ON DEA APPROACH

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ABSTRACT:

Aim: *The Aim of this research paper is to investigate whether educational inputs are able to produce desirable outputs for the system or is there any requirement of reallocation of educational resources. Investigation of the education sector's efficiency is crucial in the context of budget constraints facing all over the globe. The study assesses input and output oriented technical efficiency of states of India from 2012-13 to 2021-22 using a panel DEA approach.*

Methodogy: *In order to analyse the technical efficiency empirically, the study employs a panel dataset covering 36 states and union territories of India over the period 2012 to 2021. Due to data unavailability, Telangana is excluded from the dataset, resulting in a balanced panel of 35 states and union territories. The dataset includes three output variables, namely Net Enrolment Ratio (NER) at the elementary level (Classes I-VIII), NER at the secondary level (Classes IX-X), and the transition rate from elementary to secondary education.*

Implications: *The input and output-oriented CRS and VRS technical efficiency among states have discussed broadly in this study. • The large and populous states consistently have performed badly in both CRS and VRS methods under both input and output-oriented efficiency results.*

Findings: *The result reveals considerable disparity among states regarding efficiency under both CRS and VRS framework. The large and populous states have performed at the bottom, while smaller states have enhanced their performances. This shows that inefficiency in education among states arise both from management deficiency and improper scale of operation. The study provides important policy implications for the betterment of education sector of states.*

KEYWORDS: *Data Envelopment Analysis (DEA), Education Development Index (EDI), Technical Efficiency, Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS)*

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1. INTRODUCTION

The foundation of efficiency in resource utilization in any sector revolves around two terms- scarcity and choice (Samuelson & Nordhaus, 2010; Lipsey & Chrystal, 2015). The studies related to efficiency especially in education sector got prominence after global financial crisis, albeit a few studies were there earlier. Inefficiency in educational resources imply that the sector has potentiality to produce more output than its current production with same amount of input usage or it can reduce input quantity to produce the same level of educational output (Coelli et al. (2005). Education is regarded as the flag bearer of social transformation, economic growth, sustainability and equality (Tilak, 2003, Jha, Das, Mohanty and Jha, 2008). According to Solow (1956), country-wise differences in productivity and thereby per capita income are because of variation in Human Resource Development. Importance of education and its investment basically have evolved from growth theories of Solow (1956), Lucas (1988) and Romer (1990a, b). Lucas (1988) and Romar (1990) advocated 'New Endogenous Growth' model to explain per capita income variation among countries through the differences in human capital. Educational investments complement the growth journey through better employment and wage opportunities (Muralidharan, 2013). Becker (1993) emphasized on human capital formation for a country's growth. Empirical studies reveal among the three levels of education primary education provides highest return. Again, return is more for women education, for general curricula and for low-income countries. (Psacharopoulos, 1994).

The worldwide adoption of fiscal austerity-oriented policies in the face of growing fiscal pressure have put significant constraints on education sector that necessitate a careful evaluation of how scarce resources are utilized (World Bank (2018). Fiscal tightening characterized by curtailing of spending in many sectors, rationalization of subsidies results in reduced budgetary allocations for social sectors, making it imperative for governments to ensure that existing resources must result in desired outcome. (Alesina & Ardagna, 2013; Gupta & Tiongson, 2003). This underscores the importance of studying technical efficiency in education, which examines whether educational entities convert available inputs such as teachers, classrooms, grants, and instructional time into desired outputs including enrolment, retention, and learning achievements in an optimal manner. By identifying variations in performance, efficiency analysis provides evidence for reducing wastage, improving input mix, and targeting interventions more effectively, thereby safeguarding equity and quality even under tight fiscal conditions.

India has made significant progress in terms of literacy and enrolment over the years. The Gross Enrolment Ratio (GER) for SC children in primary and upper primary schools has increased from 96.8 to 113 percent and 65.3 to 98.3 per cent between 2000-01 to 2013-14. For ST children the same figures were 12.1 and 31.1 percent respectively in 2013. However, a high dropout rate in all the levels of education, especially among marginalized communities, is quite visible (MoSPI, 2006; UNESCO, 2014). Moreover, quality aspect of school education has failed to grown with educational investment. As per the report of ASER, the arithmetic and reading ability of students of 8th standard in India had declined from 65.2 percent and 83.6 percent in 2008-09 to 40 percent and 69 percent in 2018-19 respectively (ASER, 2018). Thus, it is important to investigate whether educational inputs are able to produce desirable outputs for the system or is there any requirement of reallocation of educational resources. This study tries to analyse input and output-oriented technical efficiency of school education of Indian states from 2012-13 to 2021-22.

2. REVIEW OF LITERATURE

The pioneering work regarding education efficiency was initiated by Charnes et al and Bessent et. al during 1980s and remarked that if there is no possibility to enhance educational output for a given level of investment or no scope to compress any input for a fixed set of educational output, then that system of education is considered as efficient (Bessent and Bessent, 1980). Thereafter, many researchers and

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policy makers analysed efficiency at different levels using different methodologies and inputs and outputs. Many of them use parametric methods like Stochastic Frontier Analysis (SFA), while others choose non-parametric methods to measure efficiency. Among the non-parametric ones, the mostly used methods are Data Envelopment Analysis (DEA) and Free Disposal Hall (FDH). Bessent et. al (1982) used DEA method to evaluate efficiency of 167 elementary schools in the Houston Independent School District. Among 167 schools, only 53.2 percent schools were found to be efficient as remaining 78 schools were inefficient as per the result. The inputs used were-enrolment and attendance rate, percentage of non-minority students to total enrolment, number of teachers per thousand students, percentage of students paying full lunch price, public spending per students, teachers' attendance, teachers' academic qualification and years of experience, number of special programmes introduced in school etc., while Iowa Test of Basic Skills for grade-iii and grade-vi were taken as outputs. A similar study was conducted to compare the efficiency differences between government and private schools of Spain by using DEA. The output taken was PISA-2006 data. They found that public schools performed better than the private ones during the study period if student's socio-economic background, school resource differences and individual management inefficiencies are not considered (Mancebón et. al, 2010). Winkler and Sondergaard (2008) analysed technical efficiency of 180 public and private schools of Uganda across 6 districts. The result of determinants of technical efficiency highlighted that improper deployment of teachers, low workload as compared to salaries were the main factors behind inefficiency of schools. Banker et. al, 2004, in their study of finding technical and allocative efficiency of Texas school districts over a period of six years, that is, from 1993 to 1999 found an increasing trend of technical inefficiency and a constant trend of allocative inefficiency during the study period. They employed panel DEA method for their study. Guzman & Cabanda (2009) also employed panel DEA method to study efficiency of private education institutions of Philippine from 2001-05. The result showed average efficiency value to be 0.807, which means approximately 20 percent institutions were inefficient in that period.

In the context of India, several studies used both parametric and non-parametric method. Chudasama (2020) made a state-wise comparison of rankings between Education Development Index (EDI) developed by NUEPA and efficiency index calculated through DEA. The study highlighted the fact that states with high performance in EDI need not necessarily efficient in input utilization. Tyagi et. al (2009) evaluated elementary education efficiency of 28 major states of India during 2009 to 2020. The average value of efficiency index was found to be 0.79 and variation in scores ranged between 52 and 94.5 percent. Several NER states like Meghalaya, Mizoram and Manipur ranked at the bottom, while states like Goa, Kerala and Haryana stood at the top. Further, the study revealed that school infrastructure, public education expenditure, literacy and urbanisation rate influence efficiency positively. In contrast to that, the percentage of SC and ST enrolment, recruitment of contractual teachers, reduces school efficiency.

3. DATA AND METHODOLOGY

In order to analyse the technical efficiency empirically, the study employs a panel dataset covering 36 states and union territories of India over the period 2012 to 2021. Due to data unavailability, Telangana is excluded from the dataset, resulting in a balanced panel of 35 states and union territories. The dataset includes three output variables, namely Net Enrolment Ratio (NER) at the elementary level (Classes I-VIII), NER at the secondary level (Classes IX-X), and the transition rate from elementary to secondary education. In addition, 14 input variables were identified: total schools per 1,000 school-aged population, teachers per school, proportion of teachers with academic qualification graduate and above, primary Pupil-Teacher Ratio (PTR), secondary PTR, functional electricity, availability of playground, availability of library or reading corner or book bank, schools having functional toilet facility, schools having functional drinking water, schools having ramps, availability of medical check-up, internet access, and computer availability.

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The multiple output nature of data makes the application of non-parametric techniques like Data Envelopment Analysis (DEA) more suitable than the parametric ones (Johnes, 2006; Ray, 2004). Moreover, DEA doesn't need a pre-specified functional form (Charnes et. al, 1978; Banker et. al, 1984) and distributional assumption about the error term (Greene, 2008). For the education sector, DEA is highly used as inputs and outputs are non-marketed in nature (Worthington, 2001; Emrouznejad & Thanassoulis, 2005). As DEA is highly sensitive to missing values, the study first addressed data gaps through interpolation and extrapolation techniques to generate a consistent and balanced panel. This ensured that all units across the 10-year period had complete information, making them comparable within the DEA framework. Following this, the input variables were aggregated into three composite indices using Principal Component Analysis (PCA). The infrastructure index was constructed using functional electricity, playground, library/reading corner/book bank, toilet facility, drinking water facility, and ramps. The quality index included the proportion of teachers with graduate and above, medical check-up facilities, internet connectivity, and computer availability. Finally, the access and availability index was derived from total schools per 1,000 school-aged population, teachers per school, primary PTR, and secondary PTR.

DEA is a kind of non-parametric technique used to measure the relative technical efficiency of Decision-Making Units (DMUs) in a multiple input-output scenario. If we assume 'm' outputs and 'k' inputs for 'n' DMUs, then X and Y can be regarded as (k x n) input matrix and (m x n) output matrix, respectively. For i-th DMU, both Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) production technologies are employed in both input-oriented and output-oriented specifications.

Under the CRS assumption, which was originally proposed by Charnes, Cooper and Rhodes (CCR), the production technology is assumed to exhibit proportional scaling. For the i-th DMU, the input-oriented CRS model is formulated as:

$$\min_{\theta,\lambda} \ \theta$$

Subject to

$$X\lambda \leq \theta x_i, Y\lambda \geq y_i, \lambda \geq 0.$$

Here, θ is regarded as the radial contraction factor where θ <1 implies technical inefficiency and θ = 1 implies technical efficiency.

The output-oriented CRS model is represented as:

$$\max_{\phi,\lambda} \ \phi$$

subject to

$$X\lambda \leq x_i, Y\lambda \geq \phi y_i, \lambda \geq 0.$$

Here, θ represents as the expansion factor for outputs. Technical efficiency is measured as 1/ θ and any value less than 1 indicates inefficiency.

The VRS model as initiated by Banker, Charnes and Cooper (BCC), relaxes the CRS assumption by allowing the scale of operations to influence performance. It imposes convexity constraints to account for increasing, constant, or decreasing returns to scale. For the ith DMU, the input-oriented VRS DEA model is specified as:

$$\min_{\theta,\lambda} \ \theta$$

subject to

$$X\lambda \leq \theta x_i, Y\lambda \geq y_i, \mathbf{1}'\lambda = 1, \lambda \geq 0.$$

The convexity constraint $1'$ λ implies that the efficient frontier is formed as a convex combination of existing DMUs and thus incorporating scale effects.

Similarly, the output-oriented VRS model is expressed as:

$$\max_{\phi,\lambda} \ \phi$$

subject to

$$X\lambda \leq x_i, Y\lambda \geq \phi y_i, \mathbf{1}'\lambda = 1, \lambda \geq 0.$$

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Here θ denotes the amount of proportional output needs to with the efficiency score of 1/ θ. The VRS structure allows the model to separate pure technical inefficiency from scale inefficiency, making it particularly useful for identifying whether DMUs are operating at an optimal scale.

4. RESULT OF OUTPUT-ORIENTED MODEL (CRS and VRS):

The output-oriented average technical efficiency scores under both CRS and VRS from 2012-13 to 2021-22 show wide variations of efficiency among the states. The output-oriented efficiency investigates how much a DMU can enhance its level of output without adding marginal input. The mean score of output-oriented efficiency under CRS (0.318) is much lower than VRS (0.964), implying the existence of severe scale related inefficiency among states.

Table 1: Output-oriented Technical Efficiency under both CRS and VRS

States	Corrected Average TE, CRS, 2012-2021	Rank	Corrected Average TE, VRS, 2012-2021	Rank	Scale Efficiency	Rank
Andaman & Nicobar Islands	0.89551554	2	0.997956828	4	0.897348979	2
Andhra Pradesh	0.062846049	26	0.948396443	17	0.066265589	26
Arunachal Pradesh	0.661040197	3	0.994985113	5	0.664371947	3
Assam	0.106966512	18	0.983139088	9	0.108800996	18
Bihar	0.054324328	28	0.906695076	22	0.059914661	28
Chandigarh	0.485665063	9	0.99980894	2	0.485757872	10
Chhattisgarh	0.078469746	22	0.936742892	18	0.083768713	22
Dadra & Nagar Haveli	0.465083095	11	0.991130461	7	0.469245083	11
Daman & Diu	0.405615823	12	1	1	0.405615823	12
Delhi	0.197947545	14	1	1	0.197947545	14
Goa	0.509569153	8	1	1	0.509569153	9
Gujarat	0.049946597	29	0.889604466	27	0.056144723	29
Haryana	0.099890984	19	0.962921365	13	0.103737426	19
Himachal Pradesh	0.346140149	13	1	1	0.346140149	13
Jammu & Kashmir	0.163662952	15	0.890792088	26	0.183727442	15
Jharkhand	0.068071495	23	0.920040994	21	0.073987458	23
Karnataka	0.064975515	25	0.961591754	14	0.06757079	25
Kerala	0.152526892	16	0.999431274	3	0.152613687	16
Lakshadweep	1	1	1	1	1	1
Madhya Pradesh	0.036095066	32	0.891944395	25	0.040467843	32
Maharashtra	0.043531147	31	0.984829291	8	0.044201718	31
Manipur	0.516266575	6	0.980191696	10	0.526699601	7
Meghalaya	0.587118217	4	1	1	0.587118217	4
Mizoram	1	1	1	1	1	1
Nagaland	0.484409427	10	0.904988639	23	0.535265755	6
Odisha	0.085820336	21	0.920240411	20	0.093258604	21
Puducherry	0.510892765	7	0.994450044	6	0.513744022	8
Punjab	0.097155791	20	0.959090741	15	0.101299895	20
Rajasthan	0.045783423	30	0.932591774	19	0.049092673	30
Sikkim	1	1	1	1	1	1
Tamilnadu	0.066826011	24	0.964533097	12	0.069283274	24

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Tripura	0.563551136	5	1	1	0.563551136	5
Uttar Pradesh	0.025259742	33	0.898563156	24	0.028111259	33
Uttarakhand	0.145915265	17	0.969474946	11	0.150509578	17
West Bengal	0.060305728	27	0.953935213	16	0.063217845	27
Average	0.318205379		0.963944862		0.322809985	
S.D	0.311677833		0.039166834		0.311255857	
C.V	0.979486374		0.04063182		0.96420765	

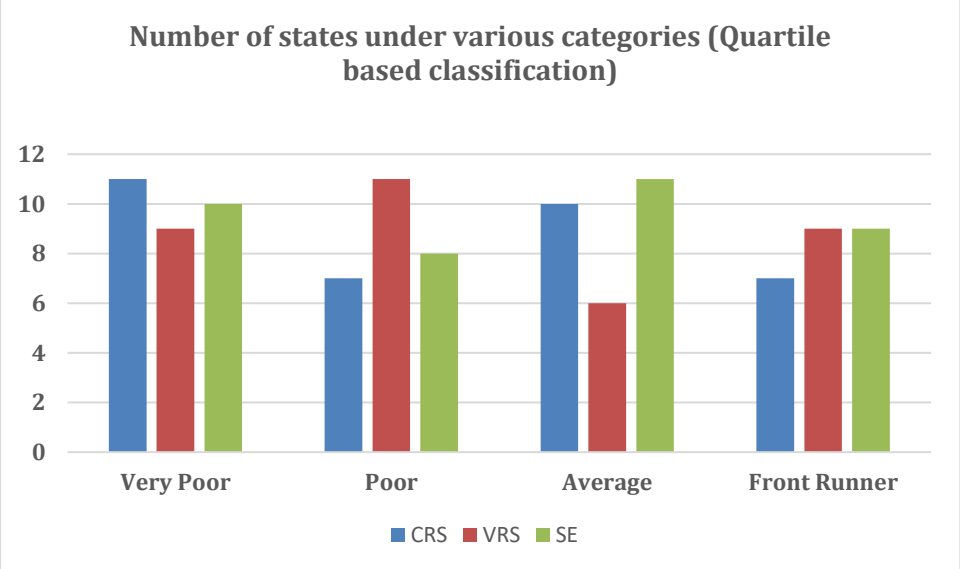
Source: Authors' calculation based on UDISE+, Census, ASER and NAS report data.

Among all states, the two of the states of NER such as Mizoram and Sikkim and the union territory of Lakshadweep have performed extremely well in all three categories, signifying their scale as well as managerial efficiency. The CRS efficiency score captures both scale and managerial efficiency. The CRS technical efficiency value ranges from 0.025 in Uttar Pradesh to one in a few small states. However, the variation in VRS efficiency is lower as reflected by a lower C.V value, indicating that states are relatively efficient in resource management but are facing the problem of improper scale of operation, as VRS shows pure technical efficiency independent of size. The scale efficiency, which is the ratio of CRS to VRS, shows that the large and populous like UP, Assam, MP, Bihar etc. have displayed low scale efficiency which means that educational outcome of them could be improved if they operate under optimal scale. In opposite to that, smaller states like Mizoram, Sikkim, Arunachal and union territories like Goa, Lakshadweep, Andaman and Nicobar have achieved high scale efficiency.

Table 2: Quartile based classification of Output-oriented TE under CRS, VRS and Scale Efficiency

Quartile	Percentile Range	Category	Approx. CRS Range	Approx. VRS Range	Approx. S.E Range
Q1	0–25th	**Very Poor**	<0.06	< 0.934	< 0.06
Q2	25th–50th	**Poor**	0.06-0.15	0.934 – 0.98	0.06 – 0.15
Q3	50th–75th	**Average**	0.15-0.51	0.98 – 0.99	0.15 – 0.52
Q4	75th–100th	**Front Runners**	≥0.51	≥ 0.99	≥ 0.52

Source: Authors' calculation based on output-oriented technical efficiency scores.



Source: Authors' calculation based on quartile values.

The quartile-based classification of output-oriented efficiency scores highlights that only seven states have come under front-runner category under CRS. The numbers have increased to nine in both VRS and Scale efficiency category. Under CRS, several NER states like Tripura, Meghalaya, Sikkim,

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Arunachal Pradesh, Mizoram and two union territories Andaman & Nicobar and Lakshadweep have qualified as top-runners. Delhi, Himachal Pradesh, Daman & Diu and Jammu & Kashmir come under average category. The states that have been performing under poor category are-Chhattisgarh, Odisha, Punjab, Haryana, Assam, Uttarakhand and Kerala. The remaining large states such as Uttar Pradesh, Madhya Pradesh, Maharashtra, Gujrat, Bihar, West Bengal, Andhra Pradesh, Karnataka, Tamil Nadu and Jharkhand come under very poor performer category.

The rankings under scale efficiency are almost similar to CRS rankings, only Jharkhand and Manipur have improved from very poor to poor and average to front runner category. In VRS category, Odisha, Arunachal and Jammu & Kashmir have shown management inefficiency as their positions have dropped from poor to very poor, front runner to average and average to very poor category respectively in comparison to CRS. However, Daman and Diu, Delhi, Goa and Himachal Pradesh have improved their pure efficiency and emerge as top-runners along with some North Eastern states except Assam. Assam has performed as poor performer in CRS, VRS and Scale efficiency.

5. RESULT OF INPUT-ORIENTED MODEL (CRS and VRS):

Input-oriented technical efficiency represents efficiency in input or resource utilization. In an educational institution, if there is any possibility to compress the quantity of inputs without compromising the current level of output, then the institution is said to be technically inefficient. The analysis of input-oriented efficiency reveals wide heterogeneity among states regarding their input usage and management. The average efficiency score under CRS is 0.328 which means institutions face high deficiency in optimum scale operations and can reduce almost 67 percent of its resources to achieve similar outcome. The inequality in resource management among states is very high in both CRS (C.V = 0.95) and VRS (0.70) system. However, the scale related efficiency variation is lower in input-oriented efficiency as compared to output-oriented model. The VRS model show relatively high means score (0.53), indicating the fact that most of the deficiency comes due to not operating in optimum scale size rather than management deficiency.

Table 3: Input Oriented Average Technical Efficiency

States	CRS	Rank	VRS	Rank	Scale Efficiency	Rank
Andaman & Nicobar Islands	0.903774	2	0.989164	2	0.913675	4
Andhra Pradesh	0.066979	26	0.203147	20	0.329708	26
Arunachal Pradesh	0.664908	3	0.933614	4	0.712187	9
Assam	0.112329	18	0.206171	19	0.544836	18
Bihar	0.057486	28	0.067582	27	0.850614	5
Chandigarh	0.488085	11	0.948348	3	0.514669	20
Chhattisgarh	0.082379	22	0.165715	21	0.497114	24
Dadra & Nagar Haveli	0.468171	12	0.915199	5	0.511551	22
Daman & Diu	0.444976	13	1	1	0.444976	25
Delhi	0.200535	14	0.868737	6	0.230835	29
Goa	0.514172	7	1	1	0.514172	21
Gujarat	0.051945	29	0.077613	25	0.669285	11
Haryana	0.101747	19	0.164839	22	0.617254	13
Himachal Pradesh	0.504674	9	1	1	0.504674	23
Jammu & Kashmir	0.173027	15	0.225501	18	0.767297	7
Jharkhand	0.074053	23	0.077442	26	0.956241	2
Karnataka	0.071644	24	0.469426	12	0.152621	33
Kerala	0.159117	16	0.83296	7	0.191026	31
Lakshadweep	1	1	1	1	1	1
Madhya Pradesh	0.040662	32	0.057495	28	0.707227	10

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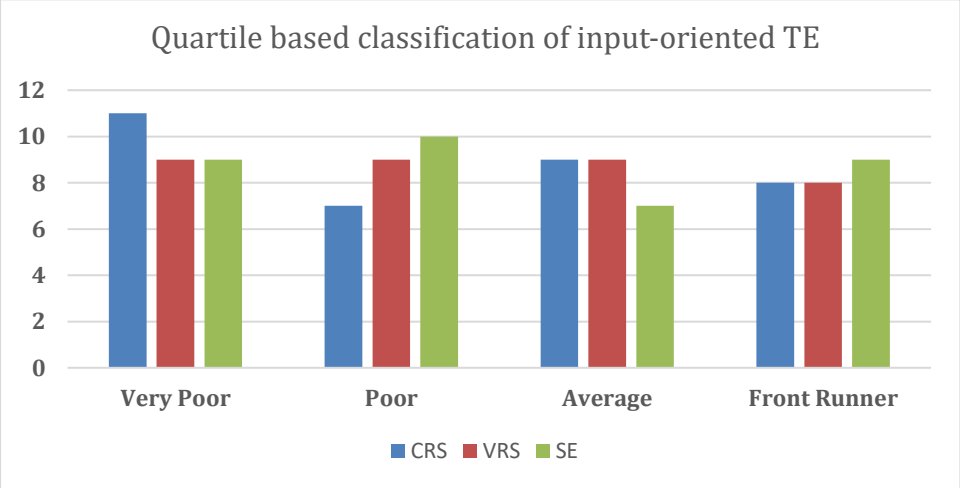
Maharashtra	0.050302	31	0.323875	15	0.155312	32
Manipur	0.521432	6	0.83067	8	0.627724	12
Meghalaya	0.625351	4	0.777334	9	0.804481	6
Mizoram	1	1	1	1	1	1
Nagaland	0.489141	10	0.521394	11	0.938141	3
Odisha	0.091979	21	0.158041	23	0.581993	16
Puducherry	0.511848	8	0.695184	10	0.736277	8
Punjab	0.100936	20	0.338276	13	0.298382	27
Rajasthan	0.05134	30	0.087179	24	0.5889	15
Sikkim	1	1	1	1	1	1
Tamilnadu	0.07141	25	0.3345	14	0.213483	30
Tripura	0.569699	5	1	1	0.569699	17
Uttar Pradesh	0.028326	33	0.047619	29	0.594843	14
Uttarakhand	0.148216	17	0.284478	16	0.521012	19
West Bengal	0.062608	27	0.247097	17	0.253376	28
Average	0.328664		0.538531		0.586102	
S.D	0.313661		0.37854		0.254713	
C.V	0.954351		0.702912		0.434587	

Source: Author's calculation based on UDISE+, Census, ASER and NAS report data.

Table 4: Quartile based classification of Input-oriented TE under CRS, VRS and Scale Efficiency

Quartile	Percentile Range	Category	Approx. CRS Range	Approx. VRS Range	Approx. S.E Range
Q1	0–25th	**Very Poor**	<0.07	<0.18	<0.47
Q2	25th–50th	**Poor**	0.07-0.16	0.18-0.47	0.47-0.58
Q3	50th–75th	**Average**	0.16-0.51	0.47-0.94	0.58-0.75
Q4	75th–100th	**Front Runners**	≥0.51	≥0.94	≥0.75

Source: Author's calculation based on quartile values.



Source: Author's calculation based on quartile values.

The quartile-based classification under CRS elucidates that eight states namely Manipur, Tripura, Meghalaya, Arunachal Pradesh, Andaman and Nicobar, Lakshadweep, Sikkim and Mizoram come under front-runner category, with quartile value greater than 0.51, indicating effective utilization of educational inputs under limited administrative setup with optimal scale. The states that come under average category under CRS with quartile value lying between 0.16-0.51 are- Jammu and Kashmir,

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Delhi, Daman and Diu, Dadra and Nagar Haveli, Chandigarh, Nagaland, Himachal, Puducherry and Goa. Again, Chhattisgarh, Odisha, Punjab, Haryana, Assam, Uttarakhand and Kerala come under poor category, indicating structural rigidities, sub-optimal allocation of resources and inefficient governance in education sector. Lastly, the very poor performers showing high inefficiency and input wastage are- Uttar Pradesh, Madhya Pradesh, Maharashtra, Gujrat, Bihar, West Bengal, Andhra Pradesh, Tamil Nadu, Karnataka and Jharkhand.

The classification of VRS efficiency measures also provides the similar pattern. The large states like Uttar Pradesh, Madhya Pradesh, Bihar, Jharkhand, Gujrat, and Rajasthan have performed at bottom. Odisha, Haryana and Chhattisgarh have moved from poor in CRS to very poor category in VRS. This pattern suggests that inefficiency in several large states stems not only from scale diseconomies but also from managerial and administrative shortcomings, such as ineffective policy implementation, suboptimal teacher deployment, and inadequate monitoring mechanisms. Among NER states, Assam has continuously performed under poor category in both CRS and VRS production technologies. In contrast to that, the other states of NER such as Mizoram, Sikkim, Tripura have continuously performed excellent in all categories.

The average scale efficiency value of input-oriented model is found to be 0.586 which means many of the states are not operating at the most productive scale size. In this category, Jammu and Kashmir, Meghalaya, Bihar, Andaman and Nicobar, Nagaland, Jharkhand, Lakshadweep, Mizoram and Sikkim come under front-runner states. Interestingly, Bihar and Jharkhand are in very poor category in both CRS and VRS models. This means that despite poor resource utilization, the overall scale of educational operations in these states is broadly appropriate. Moreover, Daman and Diu, which is in the average and front-runner category in CRS and VRS respectively, falls under very poor performer states in scale efficiency categorization. Other than that, Karnataka, Maharashtra, Kerala, Tamil Nadu, Delhi, West Bengal, Punjab and Andhra Pradesh also fall under very poor category. Again, Uttar Pradesh, Madhya Pradesh, Haryana and Gujrat have improved their positions under scale efficiency and secured average performer position.

6. Discussion and Policy Implication

The input and output-oriented CRS and VRS technical efficiency among states have discussed broadly in this study. A few notable findings from efficiency results are:

- The large and populous states consistently have performed badly in both CRS and VRS methods under both input and output-oriented efficiency results. This underscores the fact that there is misalignment between resource expansion and output convertibility. These states suffer from managerial inefficiency along with scale related deficiency.
- The efficiency scores of large states in both input and output-oriented method have improved when VRS technology is considered, implying that scale related constraints are much stronger in these states as compared to management-oriented deficiencies. However, Bihar and Jharkhand have shown different result. Despite poor CRS and VRS efficiency, they emerge as front runners in scale efficiency. It indicates that inefficiency in Bihar and Jharkhand is not primarily driven by inappropriate scale, such as excessive fragmentation or under-provision of educational infrastructure. Instead, these states are constrained by ineffective utilization of resources at an otherwise optimal scale.
- Small NER states and union territories have performed excellently. This is probably due to administrative efficiency, relatively homogeneous demography, close monitoring system and efficient utilization of educational resources.

In the context of fiscal austerity, it is important to rationalize expenditure as most of large states are found to be inefficient which means their educational resources can be reduced to find similar output or utilizing same level of inputs outputs can be enhanced to reach the optimum frontier. Thus, large

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states should focus on efficiency enhancing reforms that can rationalize inputs such as rational teacher deployment, reduction of administrative overheads, consolidation of under-enrolled schools, and improved targeting of education expenditure toward disadvantaged regions. Strengthening district and block level planning mechanisms can help align resource allocation more closely with local needs, reducing inefficiencies arising from centralized decision-making. Similarly, small states should focus on maintaining efficiency consistently with compacted administrative setup. In order to enhance output-oriented efficiency, states should emphasize on quality over quantity. For this, teachers' training and capacity building programmes, performance-based incentives, proper monitoring system, strong administrative mechanism etc. should be implemented.

9. CONCLUSION

The study has made an assessment of input and output-oriented technical efficiency of Indian states using DEA approach for both CRS and VRS framework. The result shows large variation of efficiency among states. The performance of small states has found to be quite significant as compared to large states. The combined evidence from input-oriented and output-oriented efficiency measures underscores the need for a dual policy approach. On the one hand, input-oriented inefficiency highlights the scope for resource rationalization and improved managerial practices, particularly in fiscally constrained environments. On the other hand, output-oriented inefficiency emphasizes the importance of shifting policy focus toward improving learning outcomes, institutional effectiveness, and accountability mechanisms, rather than relying on expenditure-led strategies.

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SACRED CONFLUENCE, LOCAL CONSEQUENCES: ASSESSING THE IMPACT OF MAHAKUMBH MELA 2025 ON THE LOCAL INHABITANTS OF PRAYAGRAJ

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ABSTRACT:
The Mahakumbh Mela, one of the largest religious gatherings in the world, brings significant cultural, spiritual, and economic attention to the host city of Prayagraj. This paper explores the multifaceted impact of the mela on the local residents through a structured questionnaire-based survey of 100 respondents residing primarily in the Nehru Park and Preetam Nagar areas of the Prayagraj city. The study reveals that while the event enhances the city's infrastructure, boosts tourism, and reinforces its cultural heritage, it simultaneously imposes substantial challenges on the daily lives of its residents. Key findings highlight widespread awareness and participation in the mela, with 81% of respondents having visited the event. However, major issues such as overcrowding, traffic congestion, lack of accessible transport, unpredictable barricading, and inflated prices for essential goods and services were reported by a significant portion of the population. Although 84% of respondents appreciated the support provided by administrative bodies, over one-third felt that local needs were not adequately considered in policy and planning decisions. The mela contributed positively to city development, revenue generation, and social service initiatives, yet its benefits were not evenly distributed among the local population. The study concludes that while the Mahakumbh Mela brings spiritual and developmental gains to Prayagraj, its execution must be made more inclusive and resident-sensitive. It offers policy recommendations aimed at balancing the needs of pilgrims and local inhabitants to ensure more equitable urban planning during future events.

KEYWORDS: ***Mahakumbh Mela, Prayagraj Local Population, Cultural Pride, Infrastructural Improvements***

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1. INTRODUCTION

The Mahakumbh Mela, held once every twelve years in Prayagraj, India, represents one of the most significant religious congregations globally, attracting millions of devotees, ascetics, and tourists. Beyond its religious centrality within Hindu tradition, the Mela functions as a large-scale socio-cultural phenomenon with profound implications for the urban landscape and daily life of its host city. While existing literature has largely emphasized the spiritual, logistical, and infrastructural dimensions of the event, less attention has been paid to the lived experiences of local inhabitants who must navigate the accompanying transformations within their immediate environments.

This study investigates the multifaceted impact of the Mahakumbh Mela on the local population of Prayagraj, focusing specifically on residents of the Nehru Park and Preetam Nagar localities. Drawing on data collected from 100 respondents through structured interviews and surveys, the research aims to critically assess how the Mela affects key aspects of urban life including mobility, access to essential services, economic activity, and environmental quality. The findings reveal a dualistic impact: while residents report a sense of cultural pride, infrastructural improvements, and heightened visibility of the city on a national and global scale, they also express concerns over increased congestion, inflated prices, limited accessibility, and inadequate prioritization of local needs during the planning and execution phases of the event.

Notably, although 87% of respondents acknowledged visible infrastructural development and 84% found administrative support to be generally helpful, nearly half felt that their specific needs as residents were marginalized. Furthermore, many reported negligible personal economic benefit, indicating that the broader economic gains associated with the event were unevenly distributed. Environmental degradation, overcrowded transport systems, and inconsistent public service delivery further compounded the challenges faced by the local population.

In examining the interplay between large-scale event planning and urban inhabitant well-being, this research contributes to a growing body of scholarship calling for more inclusive and participatory approaches to mega-event governance. By centering the perspectives of residents—often overlooked in top-down planning frameworks—the study underscores the importance of equitable policy design that balances the spiritual and cultural objectives of events like the Mahakumbh Mela with the everyday realities of urban life in contemporary India.

2. DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS

To assess the impact of the Mahakumbh Mela on the local inhabitants of Prayagraj, a structured questionnaire survey was administered among 100 local residents. The demographic profile of the respondents is presented below to provide context for the study findings.

- Age Distribution: - A majority of the respondents (52%) belonged to the age group of 18–36 years, indicating a predominance of young adults in the sample. The second largest group (19%) was aged between 36–54 years. Respondents under 18 years constituted 12%, while only 4% were above the age of 72. The relatively lower representation of children and elderly individuals may be attributed to restricted movement due to heavy crowding and barricading during the event, which primarily affected working individuals and school-going children.
- Gender Composition: - The gender distribution among the respondents was evenly split, with 50% male and 50% female participants. While the sample reflects gender parity, it does not align with the overall sex ratio of Prayagraj, which stands at 901 females per 1000 males, according to the Government of Uttar Pradesh (2025).
- Educational Qualifications:- Educational attainment among the respondents was relatively high. Approximately 52% held a graduate degree, while 16% had completed post-graduate education. This trend reflects Prayagraj status as an important educational center in Uttar Pradesh. The city houses major educational institutions including the Department of Higher Education (UP), the

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Board of High School and Intermediate Education Uttar Pradesh, a Central University, three Deemed Universities, and an Open University.

- Employment Status:- Employment data revealed that 52% of respondents were employed, whereas 48% were unemployed, most of whom were students preparing for competitive examinations. Among the employed individuals, 20% held government positions, 75% were engaged in private employment or self-owned businesses, and 5% worked as laborers. Notably, a majority of those involved in private businesses had been residents of Prayagraj for over ten years.
- Duration of Residence: - A significant portion of the sample (67%) had resided in Prayagraj for more than ten years, with many of them being lifelong residents. The remaining respondents had lived in the city for a period ranging from one to five years. This latter group mainly consisted of government officials who had relocated to Prayagraj due to professional postings.
- Proximity to the Sangam Area:- The survey was predominantly conducted in the Nehru Park and Preetam Nagar areas, both located near Dhoomanganj Police Chowki. These areas are approximately 11 kilometers from the Sangam. Consequently, most respondents reported that their residences were situated within 10–15 kilometers of the Sangam, placing them in proximity to the main event site and directly exposing them to the logistical and social effects of the Mahakumbh Mela.

3. Awareness Regarding The Kumbh Mela

The Kumbh Mela is one of the most prominent religious gatherings in the world, and its cultural significance in Prayagraj is deeply embedded in the local consciousness. According to the survey conducted, 100% of the respondents were aware of the Kumbh Mela. This complete awareness can be attributed to the fair's strong historical roots, extensive government promotion, and its recent recognition by UNESCO as part of the Intangible Cultural Heritage of Humanity. The event's deep cultural resonance, combined with heavy media coverage and public announcements, has ensured widespread familiarity among the city's residents. When asked about their participation in the Kumbh Mela, 81% of the respondents reported that they had visited the Mela, while 15% indicated that they had the opportunity to attend but chose not to visit the mela. Several factors contributed to the latter group's decision not to visit. These included:

- Overcrowding at the Sangam area, which made access physically challenging.
- Heavy barricading and transportation difficulties, especially affecting the elderly and disabled residents.
- Some long-term residents expressed a sense of familiarity with the Mela, noting that they had participated in previous editions and wished to give space to out-of-town visitors who had traveled long distances to attend the event.

This pattern of participation highlights not only a high level of engagement with the Mela but also a nuanced understanding among locals of its broader significance and logistical challenges.

4. Advertisement And Accessibility Of The Kumbh Mela

The Mahakumbh Mela was heavily promoted through various advertising campaigns led by both government and non-government bodies. Survey results indicate that 92% of respondents had seen advertisements related to the Kumbh Mela, demonstrating the extensive reach and visibility of these campaigns. Notably, 67% of respondents stated that they had encountered advertisements across multiple platforms, including television, radio, newspapers, billboards, and digital media. Only 7% of the surveyed population reported no exposure to such advertisements. The data reveal a clear correlation between advertisement exposure and the decision to attend the Mela. Respondents acknowledged that advertisements played a significant role in shaping their decision to visit the Sangam

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area during the festival. Promotional content likely reinforced the spiritual importance and scale of the event, motivating people to make at least one visit during the Mela period.

However, despite this influence, most residents visited the Sangam area only once throughout the event duration. This limited frequency was primarily due to practical concerns such as overcrowding, long walking distances, and restricted access caused by barricading.

The primary motivation for visiting the Mela was religious, especially for the purpose of taking a Holy Bath at the Sangam, reflecting the deep-rooted spiritual beliefs of the local population. Secondary reasons included entertainment**,** official duties, and educational interest. A notable observation is that 72% of respondents stated that neither they nor their family members participated in the Kalpwaas, a form of spiritual retreat practiced during the Mela. This is attributed to the fact that most participants were permanent residents of Prayagraj and thus did not require accommodation in the temporary tent city. Accessibility to the Kumbh Mela, particularly the Sangam Ghat—the central site of pilgrimage—was a significant factor influencing the experience of local residents during the event. The survey responses revealed a mixed perception regarding ease of access, largely influenced by crowd density and transportation restrictions. Respondents reported using private transportation to reach the Sangam area, particularly on non-peak or non-Snan (non-bathing) days. On such days, when crowd levels were relatively low, private vehicles were permitted to enter areas closer to the Ghat. However, on major Snan days, due to heavy footfall and crowd control measures, roads were blocked and private vehicles were not allowed. As a result, many residents had to resort to a combination of walking and available transport options. The survey indicated that most participants found reaching the Sangam Ghat to be moderately easy to very difficult. The primary challenge identified was the long walking distances required due to traffic restrictions and security barricades. These barriers were particularly burdensome for the elderly and those with mobility issues, limiting their participation during peak days of the event. Due to the necessity of walking, many residents incurred minimal or no travel expenses**,** especially those who lived nearby. Others reported moderately expensive travel costs when forced to combine multiple modes of transport, such as rickshaws, shared autos, or longer-distance private vehicles, especially when parking far from the event site.

5. Overcrowding And Barricading In The City

The Mahakumbh Mela draws millions of pilgrims from across India and the world, transforming Prayagraj into a densely packed religious hub. While the event holds immense spiritual and cultural significance, it also presents logistical challenges—particularly for the city's permanent residents. The survey revealed that 100% of respondents observed a significant increase in crowd density throughout the duration of the Mela. Notably, 90% reported that the crowd level was "very high" compared to normal days. The intensified population pressure during the event period disrupted daily routines, with 70% of respondents stating that they faced challenges in commuting within the city, even for essential activities such as work, education, and healthcare. This highlights how the influx of visitors during the Mela significantly affected the city's livability for locals. A critical issue raised by residents was the unpredictable and frequent barricading of roads**.** 90% of respondents reported experiencing barricading during the Mela, not only near the Sangam area but also throughout various parts of the city. The barricades were often erected or removed without warning; as one respondent noted, a road that was open just five minutes earlier could be blocked upon return. Such inconsistency in traffic control measures created widespread frustration, as locals found it difficult to plan even short commutes. Importantly, these restrictions were not limited to pilgrims—residents who were not visiting the Mela still faced movement limitations within their own neighborhoods. In terms of infrastructure and support, feedback on facilities provided to local residents was mixed. While some respondents acknowledged the availability of dedicated facilities to help locals access the Mela area, an equal number felt that such facilities were inadequate or non-existent**.** Additionally**,** 25% described the facilities as moderate**,** suggesting a partial but insufficient effort to address the unique needs of the city’s permanent

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population. The inconsistency in service provision further compounded the difficulties posed by crowding and barricading.

6. Positive And Negative Effects Of The Kumbh Mela For The City

Positive Impacts

- **Infrastructure Development**

One of the most widely acknowledged benefits of the Kumbh Mela was the improvement and expansion of urban infrastructure. 87% of respondents noticed the maintenance and development of roads, bridges, railways, and public spaces. The city was beautified with murals, graffiti, and lighting installations. This urban renewal improved the overall aesthetic and functionality of the city, even beyond the Mela period.

- **Spiritual and Social Unity**

The Mela fostered a sense of religious fulfillment and spiritual upliftment, and several residents noted that the event promoted social unification, bringing together people from different economic and social backgrounds. Charitable acts were also prominent, with 84% of respondents observing the distribution of food, clothing, and blankets to the needy.

- **City Visibility and Tourism**

The global recognition of the Kumbh Mela—bolstered by its UNESCO status—significantly boosted the popularity and international image of Prayagraj**.** This resulted in a surge of domestic and international tourists, increasing awareness of the city's cultural importance.

- **Economic Boost**

The Mela generated economic opportunities through tourism, local business activity, tent cities, hotel bookings, and services like auto-rickshaw rides and retail sales. However, it is important to note that most residents did not report a significant change in personal income, although the city's overall economy did benefit.

- **Efficient Administration and Cleanliness**

84% of respondents found administrative bodies, especially the police and railway officials, helpful and responsive. Despite the crowd, 84% also said that cleanliness in the city was well-maintained, reflecting successful sanitation management during the Mela.

Negative Impacts

- **Overcrowding and Traffic Congestion**

The most pressing issue identified by locals was overcrowding, with 100% of respondents noticing a surge in population, and 96% experiencing traffic congestion. On peak bathing days, travel times stretched dramatically—even short distances could take hours. Local mobility was severely hampered.

- **Unpredictable Barricading and Accessibility Challenges**

90% of residents reported experiencing barricades, which changed frequently and without notice. Locals often had to walk 11–15 kilometers, regardless of age or physical ability, to reach the Sangam area. This made the site inaccessible for elderly and disabled individuals, and no dedicated routes or services for locals were provided.

- **Increased Cost of Transportation and Goods**

Residents experienced a sharp increase in auto-rickshaw fares, in some cases up to 10 times the normal rate, driven by congestion and longer travel times. 57% of respondents also noted price hikes or scarcity in daily-use commodities, particularly in areas closer to the Mela.

- **Pollution and Environmental Pressure**

The influx of vehicles and the dust they generated led to noticeable increases in air pollution, causing health concerns for some residents.

- **Pressure on Public Services**

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Railway stations and trains were heavily overcrowded, with 81% of people needing 3–4 extra hours to reach the station. Despite temporary tent hospitals near the Mela, no permanent healthcare infrastructure was added for residents, and no special arrangements were made for their transportation needs.

- **Safety and Accessibility Concerns**

Many respondents felt it was unsafe or too difficult to bring elderly people and children to the Mela area due to the crowd and long walking distances. Additionally, there were no prioritized routes or facilities for locals, placing them on equal footing with tourists in terms of travel burden.

7. CONCLUSION

The Mahakumbh Mela, a religious and cultural event of immense magnitude, holds significant spiritual and socio-economic relevance for the city of Prayagraj. This study, based on the responses of 100 local inhabitants primarily from Nehru Park and Preetam Nagar areas, aimed to explore the multifaceted impact of the Mahakumbh Mela on local residents. The findings clearly indicate that while the mela brings numerous infrastructural improvements, cultural pride, and economic opportunities to the city, it also imposes several challenges for its residents—particularly in terms of mobility, accessibility, and daily convenience.

A considerable majority of respondents affirmed the administrative preparedness and the spiritual importance of the mela, with 81% having visited the event and nearly all recognizing its presence through widespread advertisement. However, these benefits were accompanied by concerns over overcrowding, traffic congestion, inflated prices for basic services and goods, and long walking distances to key locations such as the Sangam ghat—issues that affected locals' routines and access to resources. Despite 84% of respondents acknowledging administrative assistance as helpful, and 87% recognizing visible infrastructure development, nearly half still felt that the unique needs of local residents were not adequately prioritized in planning and policy-making.

The mela spurred temporary but in this sort time also it had visible changes in the city's environment such as increased charity, decorated cityscapes, and higher tourist influx that resulted in both intangible cultural promotion and tangible revenue generation. Yet, for the everyday life of the citizens, the challenges of barricading, limited transport, overcrowded railway stations, and increased pollution levels often outweighed the direct personal economic gains. Most locals did not observe any significant changes in their income or living costs, suggesting that while the city as a whole may have benefited, the distribution of those benefits among residents was uneven.

In conclusion, the Mahakumbh Mela presents a dual impact on Prayagraj local population: fostering a sense of cultural pride and facilitating city-wide development on one hand, while causing disruptions to daily life and highlighting gaps in inclusive urban planning on the other. Future planning of such large-scale events should aim for a more resident-centric approach, balancing the needs of the incoming pilgrims with those of the city's permanent residents—ensuring that development is both participatory and equitable.

8. POLICY RECOMMENDATIONS

In light of the findings from this study on the impact of the Mahakumbh Mela on the local inhabitants of Prayagraj, several policy recommendations can be made to ensure a more inclusive, sustainable, and locally-sensitive approach to the planning and execution of future mega-events:

1. **Prioritized Local Access and Mobility**
   Special transportation arrangements should be made for local residents, especially the elderly, children, and those with disabilities. Dedicated local routes, resident ID passes, and shuttle services to critical locations like Sangam ghat could significantly ease mobility challenges.

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Special corridors should be assigned within the city for the people who want to places other than the Sangam ghat, for example the markets, offices, schools etc.

2. **Transparent and Predictable Barricading Protocols**
   If possible clear, publicly announced barricading schedules and alternate route information should be disseminated in advance to minimize confusion and commuting difficulties for locals. Though it is also a fact that for handling such a large crowd barricading is very much required but some alternative ways should be made for the people visiting the other places.
3. **Equitable Resource Allocation**
   While infrastructure development is a major benefit of the mela, future projects should explicitly include enhancements to facilities that locals use regularly—such as markets, schools, hospitals, and parking areas—ensuring long-term community benefits.
4. **Price monitoring and Regulation**
   Authorities should monitor the pricing of transportation and essential commodities during the mela period to prevent price gouging by private service providers, especially in auto-rickshaws and local markets. Proper supply of the daily commodities should be ensured to check the inflation.
5. **Enhanced Public Transport Availability**
   Reliable and frequent public transport should be maintained throughout the mela period, with clear information systems and affordability for local users. Presently the public transports were functioning very well in the beginning but in later stages their accessibility became quite limited. A Proper coverage of the whole city should be ensured.
6. **Targeted Communication and Feedback Mechanisms**
   Set up local help centers and digital platforms for residents to voice their concerns, offer feedback, and access real-time updates about changes in routes, services, or emergencies during the mela period.
7. **Health and Environmental Safeguards**
   Given the pollution concerns raised by locals, stricter control over vehicular emissions, road dust, and waste management should be implemented. Additionally, permanent or semi-permanent medical facilities, beyond temporary tent hospitals, should be considered.
8. **Inclusive Planning Committees**
   Involve local resident associations, educational institutions, and civil society groups in the planning stages to ensure a more balanced and grassroots-informed development model.

By incorporating these recommendations, future editions of the Mahakumbh Mela can become more harmonious with the lives of local inhabitants—enhancing its spiritual significance without compromising the daily functionality and well-being of the host city.

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EXPLORING THE TRIANGULAR INTERSECTIONS OF FOOD, ENVIRONMENT AND SUSTAINABILITY THROUGH DIANE WILSON'S THE SEED KEEPER: A STUDY ON AGROECOLOGICAL PARADIGMS

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ABSTRACT:

The Aim of this research paper is to create awareness on the importance of soil health, traditional farming practices and the sustainable agriculture in the select literary novels. This paper underscores the purpose of study through the various questions raised around food in the post-anthropocentric world. The practice of agroecology becoming one of the solutions to the food security and rebuilding the ecosystem that is more accommodative. The paper evaluates the significance of food, the way it is produced, consumed and its effects on human health. The results of the paper explore the trajectory of food in agriculture and how literature has accumulated the relationship between the food and agriculture and invokes the idea of sustainable growth in the new world of post-anthropocentricism. The methodology of the research paper is qualitative in nature.

This paper underscores the purpose of study through the various questions raised around food in the post-anthropocentric world. They are,

1. ***Whether the food that are available to people secure?***
2. ***How soil health is related to food health?***
3. ***What the various practices in agricultural area affecting the food and human health?***
4. ***What the after affects and causes of the anthropocentric world?***
5. ***Whether the food produced in the world meet the needs of every single people in the world?***
6. ***How the world of climate crisis identifies the food?***
7. ***How people are occupied by the dilemma concerning the food they consume are secure?***
8. ***How food has become the main deficient factor in causing various health problems?***
9. ***Identifying the intersections of soil, food and human health through the work Diane Wilson's The Seed Keeper.***

KEYWORDS: ***Soil Health; Traditional Farming Practices; Sustainable Agriculture; Agroecology Practices; Literature Contribution; Diane Wilson's; The Seed Keeper***

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1. INTRODUCTION

Literature has depicted many types of environmental texts written from centuries back, there have been Natural histories like Gilbert White's *The Natural History and Antiquities of Selborne*, and field notes, travel guides, naturalist diaries, philosophical and scientific texts, travel and adventure writing, advocacies and autobiographies which includes nature at different forms. Literature has been conscious in representing the ecological consciousness, to bring out the voice of the land with non-living things and its life forms. This consciousness includes representing land and its components as a common human heritage, offering scientific insights into nature, imbuing the writing with a sense of discovery and wonder at nature and its components, demonstrating a dependence of human life on Nature, seeking to develop an ethical attitude towards nature incorporating compassion, care and responsibility, drawing attention to emerging and possible crisis in the environment basically like climate change and pollution. The ecological Imagination in literary texts often includes a concern for processes and conditions that affect the interconnectedness in nature of life forms and the ecosystem are industrialization, climate change, pollution, genocide of animals and the loss of rural ways of life and habitats.

The thought of human materialization and nature within which commercialization, spending and getting, earning a living has all let to the humans distancing them from nature and which brought the loss of loss of the very heart of humanity. This idea was depicted clearly by Wordsworth in *The World is Too Much with Us,* he says,

The world is too much with us; late and soon,
Getting and spending we lay waste our powers:
Little we see in nature that is ours;
We have give our hearts away are sordid boon! (2-4)

Wordsworth sees human life as having altered nature, then there has evolved the commercialization, earning a living, getting and spending, this daily life activities of the humans has changed the ecosystem. He also states the broken bond between the humans and Nature and indicates that the human hand that has destroyed and disturbed the Nature, he indicates this in his poem, *The Ruined Cottage,* he says,

Beside yon spring I stood
And eyed its waters till we seemed to feel
One sadness, they and I. For them a bond
Of brotherhood is broken: time has been
When every day the touch of human hand
Disturbed their stillness and they ministered
To human comfort (Wordsworth "The Ruined Cottage")

Many other writers who has depicted the majesty, beauty, the dependence of the man have on the nature as stated in the *Eagle* poem by Joy Harjo, the poem clearly states that the human cannot have a self without the nature, humanity needs to reach out Nature, because nature constitutes us, thus the humans cannot think of the self that is not open to, made of, and supported by the world around, the ecosystem. Percy Shelly's *Mount Blanc* states the nature's awesome majesty, violent, powerful, limitless, inspiring awe and fear, beyond the comprehension of the human mind.

Humans and animals in their representations are part of their larger web, in *Above Pate Valley*, Gary Snyder says human presence in nature is marked by the lethal instruments; the human presence is marked by weapons and instruments that are potentially lethal to the environment. Thus, human effects on the environment will last long for 10000 years. We damage the land, air, water; we damage it for the other creatures as well. Anthropocene is an essential term, it points to the fact that the humanity has been the single largest contributor to the crisis which we now face most notably in the form of the climate crisis.

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Human presence is what is lethal, it is appropriate to conclude with Rachel Carson's, who speaks about the history of the life on earth as the history between the living things and its surroundings. She is pointing to the linkage between the humanity with nature. But this linkage is precisely the reason why humans ought to be more careful, more compassionate, and more responsible in greed and instrumental view of the world. We look at nature available to serve us, as something available for us to exploitation, it is very instrumental view. Our indifference and our imperialist instrumental view of the world have enabled us to misuse the linkage that humans had with the nature for our purposes. And every time we damage the world through any particular practices that we had, we damage the world for many other species as well. Primary Quarries that people find are,

1. Why literature is talking about the climate crisis?
2. What forms of literature are appropriate to talk about the climate crisis?
3. And it is no longer the climate change but climate crisis.
4. What kinds of literature would be appropriate for the age of crisis?
5. What kinds of novels or poetry are would bring home to us the urgency of the situation as we are a planet we are in now?

2. OBJECTIVES OF THE RESEARCH

1. To create awareness on the importance of soil health, traditional farming practices, the sustainable agriculture in the select literary novels.
2. To understand the importance of the soil health is proportionate to food nutrient cycle
3. To explore the current issues with farming practices like, homogenous crops with external injuries and inputs
4. To understand the current problems like climate crisis, increase in hunger and malnutrition, expansion of land area, still there is insufficient food supply to meet the population of the world.
5. To evaluate the contribution of literature to Agroecological study incorporating food and agriculture.

3. LITERATURE ADDRESSING CLIMATE CRISIS

The literary shapes imaginations, by not only documenting the world as it is but also as it could/ought to be in the present and future. It enables the imagining of the past and future disasters with a view to shaping and modifying the present. It enables the imaging, also, of alternative worlds (both utopian (all to perfection) and dystopian (power struggles and violence, oppression and tyranny continue to trouble humanity)), and proposes ethics that address the planet, the human and more-than human. Literature address some ethics that would address planet as a whole, it shows us an ethics which is not, only about the human but about more than or other than the human.

The effects of humans on the earth, has not only depleted the other resources and life forms but has created lifelong effects on the people too. The food that is produced and provided has so many effects on the health of the humans. Thus to indicate the security of the food and sustainability of food the author Diane Wilson in her work The Seed Keeper takes a grandeur march in indicating the difference in producing the primary organic goods or the raw materials naturally. The corporative seeds and the raw materials have a lasting impact on the health of the people. By securing the healthy soil, in it proportionate in having the good health for the humans.

4. THE PRIMARY IMPORTANCE FOR A HEALTHY SOIL

The author of the work, *The Soil and the Health* states as, "A fertile soil, that is, a soil teeming with the healthy life in the shape of abundant micro flora and micro fauna, will bear healthy plants, and these, when consumed by animals and man, will confer health on animals and man" (Howard xv).

The importance that lies in studying the soil health is relatively interconnected with food and human health, the reason is that the author says, "the global food system is not delivering good nutrition

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for all …a profound transformation is needed to meet the challenges of persistent nutrition, rural poverty and consequences of climate change" (Wezel 1). Thus agroecology becomes a factor of solution, concentrating on, "Building healthy soil rich in organic matter and conserving soil and water" (Anderson 13).

5. ANALYZING THE NOVEL THROUGH PERSPECTIVES OF AGROECOLOGY

The novel *The Seed Keeper* by Diane Wilson starts with the protagonist named Rosalie Iron Wing, the only daughter of Ray Iron Wing and Agnes Kills Deer. Rosalie's mother died at a young age, she was raised by her father. Her inspiration and life lessons come from the way her father brought her up. They lived on the land called Minnesota, "Mnisota Makhoche, named for water so clear you could see the clouds' reflection" (Wilson 1) which was passed down by generations, "all the way back to a time when herds of the giant bison and wooly mammoth roamed this land" (Wilson 1). The survival through a healthy soil and soil's life in itself in the book, *the soil will save us,* and the author says, "when we stand on the surface of the earth, we're top a vast underground kingdom of microorganisms without which life as we know wouldn't exists" (Ohlson 8)

The Iron Wing family is known as Dakota people, they were so connected to the mother earth, Rosalie's father and the ancestors of the Dakota people believed that their survival on the land thrived by the good relationship with the mother earth, as, "we are Dakota, our name for ourselves, which means 'friendly.' We are civilized people who understand that our survival depends on knowing how to be a good relative, especially to Ina Maka, Mother Earth" (Wilson 2)

Ray Iron Wing gives the richness of the soil and the land that had been co existed by the people, the interdependency the people celebrated with nature and animals as,

Over thousands of years, the plants and animals worked with wind and fire until the land was covered in a sea of grass that was home to many relatives. The bison gave us everything, from thado, our meat, to our clothing and thipi hides. His dung fertilized the soil. The prairie dogs opened up tunnels that brought air and water deep into the earth…The prairie showed us for many generations how to live and work together as one family (Wilson 2).

Timothy Morton gives out the idea of ecology and ecological thought as a form of interconnectedness and co-existence, she says,

…ecology isn't just about global warming, recycling, and solar power—and also not just to do with everyday relationships between humans and nonhumans. It has to do with love, loss, despair, and compassion. It has to do with depression and psychosis. It has to do with capitalism and with what might exist after capitalism. It has to do with amazement, open-mindedness, and wonder. It has to do with doubt, confusion, and skepticism. It has to do with concepts of space and time. It has to do with delight, beauty, ugliness, disgust, irony, and pain. It has to do with consciousness and awareness. It has to do with ideology and critique. It has to do with reading and writing. It has to do with race, class, and gender. It has to do with sexuality. It has to do with ideas of self and the weird paradoxes of subjectivity. It has to do with society. It has to do with coexistence (Morton 7)

Rosalie comes back to her father's home after death of her husband, John, who was a white farmer, descendent of German immigrants, leaving behind the responsibilities on the shoulders of her son. After coming back home in winter, she reminisces in the teaching of her father, as he used to say, "winter, was a season of rest, when plants and animals hibernate." (Wilson 4). During her travel when she met with branches of trees in orchards, "my father believed that any plant not grown in the wild was nothing more than a weak cousin to its true self" (Wilson 3). The memories, "like the smell of wet leaves after the rain, or the rough feel of wool blanket" (Wilson 4) gave her the taste of past. She even imagines long past this winter cold there comes new lives like,

Plants would explode overnight from every field, a sea of green corn and soybeans that reached from one horizon to the next. Newly birthed calves and foals would stagger after their mothers on thin, wobbly legs. People smiled more in spring, relieved to have survived another winter. (Wilson 5).

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The travel cost her to see many places, Minnesota River, "a fast-moving relentless force that carried along everything in its path" (Wilson 5), Milton, the region under Dakota reservation, old quarry, Birch Coulee Battlefield, "one of the big battle sites from the 1862 Dakota War" (Wilson 6). This Dakota war changed Iron Wing family significantly. The ancestors fought the war with Dakota warriors, aftermath of the war took long time to heal the grief and loss it created. The Iron Wings tried farming but they struggled to survive at various natural and societal factors, "The Iron Wings tried farming but lost their harvest to grasshoppers and drought. Overtime the family was slowly picked up by tuberculosis, farm accidents, and World War II" (Wilson 7). When Rosalie's father described about this war to her, he says, "He said forgetting was easy. It's the remembering that wears you down."(Wilson 6). After long travel she gets home, "After twenty-eight years, I was home." (Wilson 7).

The long left owner had returned home, the shattered old home but it was this homeland that she dreamt in her dreams as, "this land where my family had lived for generations, land protected from farmers and developers, by its bony soil and steep slope toward the river" (Wilson 8). She couldn't believe the return to her old home, "I was afraid to touch anything, afraid it would all turn into dust or become a dream from which I would wake" (Wilson 9), the condition of the house led her remember the hospitality provoked in the heart of her father, "it was better to let hunters use the place than to have them break the window."(Wilson 8). Coming home for Rosalie looked like, "Coming home was like swimming upstream, searching for the beginning, for the clean unmuddied waters of my childhood" (Wilson 10).

6. INDICATING THE DIFFERENCE IN TRADITIONAL AND MODERN WAY OF APPROACHING NATURE

In representing the character of Rosalie's father, the man so connected with plant and animals finds his peace in them, "he was at peace in these woods" (Wilson 14). Even in collecting plants he insists Rosalie to get permission from each plant before plucking them as a means of thanking them, "teaching me from the time I was little how to ask each plant for permission to gather it" (Wilson 14). Rosalie in her childhood grew with no external facilities, like electricity, running water but with the relatives of woods, "No running water, no electricity. An outhouse. Surrounded by woods full of wild animals" (Wilson 16). The sustainability the protagonist finds in forests represents as, "This had been our grocery store, as well as my classroom and play area" (Wilson 19).

The difficulty and hardness in farming, which really has the capacity to drain one's physical and mental boundaries, always tests the borders of one's comfort and breaks them out with new energy and improvement. The process of difficulty in working on the fields, described by Peter, "I can't imagine why anyone would ever want to be a farmer" (Wilson 48). Carl also supports the point of Peter as, "Nothing but blood, sweat and tears. And more sweat" (Wilson 48). John overheard the conversation of the two, asked the opinion of Rosalie, whether she also has the same opinion, but she replied she doesn't know about detasseling, but she likes the sound of the wind crossing the corn field, "But I like hearing the wind in the corn." (Wilson 48). Rosalie also identifies her inexperienced in detasseling the corn and the difficulties in working on those difficult lands as,

> *As we moved slowly down the first row, my tennis shoes sank into rain-drenched mud. Water from the corn leaves soaked my sleeves and pants. Halfway down the row, my shoulders ached and my arms grew heavy. As the sun rose higher, the temperature climbed into the eighties, turning the black garbage bag into a steamy, sweaty nightmare. (Wilson 46)*

7. AGRICULTURE, A WAY OF LIFE

Earning a living through farming and agriculture, being the only producer of the raw materials in the cycle of the economy of consumerism and commercialization brings in a difficulty to earn a

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proper income. Rosalie depicts the hardness in it as, “Only the thought of a paycheck kept me going, kept me moving long past the paint when my muscles burned, my hands shook from fatigue, and sweat poured down my face.” (Wilson 46)

John’s selection to be farmer, he was raised in farms. He loves the environment to which he cannot part from, “Never really thought about it. I was raised up working these fields. Can’t imagine living anywhere else…I like seeing the sunrise. I like the smell of fresh- turned soil.” (Wilson 48). Peter and Carl go to apply at the college for their fall classes on the next day. John gives the pair of gloves and tall rubber boots for the mud. Farming could be hard but it also acts like a healer and great supporter, and also carries the innocence of child, brings happiness to the people during their hard work as Rosalie finds hardness of the field, but also its totality of peace in it as,

> If I made a mistake of looking around and seeing nothing but corn on every side, sometimes I struggled to catch my breath, feeling the edge of panic as if I could get lost in the long row. I had to stop, close my eyes, and listen to the soft rustle of wind moving through the leaves, as if the corn was singing just loud enough for me to hear (Wilson 49).

John and Rosalie share friendliness in sharing their experiences, as when she finds it not safe to stay with a man alone, he replies that she has no reason to be afraid of him. He says, “You have no reason to be afraid of me. I don’t know how they treat you in town, where you live, but I ain’t like that. My mama raised me to respect women.” (Wilson 50). He also refers to his father, “He raised me to know a hard day’s work. To respect money. To always try to better myself.” (Wilson 50). The fear of losing his farm also prevailed in the heart of John as, “I never really wanted to do anything but farm…Now I’m just trying to hang on. I don't want to be the one who loses this place. Sometimes the worry gets to me, is all” (Wilson 50). John offered to show the house to Rosalie, he has lived there for years, and it's passed down from several generations, “ My family has lived in this house all the way back to the original homestead in the 1860s …Every generation has tried to add on and built it up a bit more. At least until it came to me” (Wilson 50). In the eyes of Rosalie, the house was well built to withstand the farm life. She expresses the involvement of the government, “I didn’t ask if he knew who had lived here before his family, before the government cut the woods and prairie into 160-acre pieces. I had no patience for teaching people their own history” (Wilson 50).

The break time conversation broke on Rosalie’s past, “My past was too raw, too unfinished for me to put into words. Finally, I said…Never knew my mother. My dad went out hunting one morning and never came back. They told me his heart gave out.” (Wilson 52). She unravels,

We were already living in the cabin that my great-great- grandfather had built north of here, the place where I was born. He didn’t like people all that much, brown or white, and said it was better for him to be away from all the drinking in town. He decided we could take care of ourselves. He knew how to hunt and trap, and homeschooled me until he died. Taught me how to snare a rabbit and know the stars by their real names (Wilson 52).

7.1 The difficulties of farming:

Working on the field under mid-day sun was hard, John and Rosalie took a shade under the tree to be out of sun and she unfolds the importance of mulching happening naturally as, “The temperature was much cooler beneath the shelter of the old oak trees, a loamy scent rising from leaves that had decayed underfoot.”(Wilson 52). Man locating and clearing the forest for decades, Rosalie bends on it as, “ Since most of the original forest had been cleared decades earlier, I was surprised that John’s family had kept this ten-acre piece of woods” (Wilson 53). The importance of water to farming, and the selection of farmlands near water sources depicted as, “This was prime farmland, riding along a bluff on the Cottonwood River, a small offshoot that eventually joined the Minnesota River farther east. At least his family had the good sense to settle near water” (Wilson 53). John’s parents loved the woods, “Ma liked the woods so well that my daddy never had the heart to clear this piece of land” (Wilson 54).

She has named the chicks with pet names as they were her close relatives experiencing the coexistence with them, "Curly Girl, Snowpants, and Big Red" (Wilson 70). And this coexistence and love for domestic animals is clearly led out when John's father cried once in his whole lifetime is when they had to sell the horses that they brought up, "Back in the day, he grew up using horses to plow the fields. Only time I ever saw the old man cry was when we had to sell those horses" (Wilson 71). This happened because tractors came into existence,

> Needed the money. We couldn't afford to keep them on, not after we bought a tractor that needed repairs and gas. Horses were another mouth to feed. I don't think my dad like farming so much after they were gone. Said he didn't like the way things were changing (Wilson 71)

John's father depicted farming through Agroecological methods, "it includes recycling nutrients, and energy on the farm …enhancing soil organic matter and soil biological activity" (Altieri, et al, 588), most importantly conveying the farmers' responsibility in caring for a good soil,

> He used to say that farming was about taking care of your family. If you had it figured right, everything worked together. Horses pulled the plow and their manure was used to fertilize the fields. A good farmer rotated his crops, took care of his soil. That's how my daddy learned it and that's what he taught me and Eddie. But things started changing after World War II. Hybrid seeds, chemical fertilizers, new equipment. Farmers like my dad got left behind. (Wilson 71)

The winter got over. Rosalie finds a new rhythm in spring, "the way a farm came alive in the planting season" (Wilson 71). During her process of cleaning the room, she finds, "Edna's Seeds" (Wilson 73) that was left by John's mother, who saved the seeds for future generations. She starts to admire the texture, uniqueness the seeds were holding in them, "starting with "Edna's German Tomatoes" and "Judith's Early beans"… admired how unique they were. The smooth teardrop of the squash, the dark oval of the bean"(Wilson 73). She starts to associate with the seeds, "We spent the morning together, the seeds and me, and by noon I felt we were well on our way to becoming acquainted" (Wilson 73). The eagerness she had in planting them and to find the warmth of life coming out them, "I had felt the quickening in the seeds when they were exposed to the light, when they felt the warmth of my hand"(Wilson 74).

Side by side, John starts to prepare his soil for the next harvest, he stands admiring the freshly turned soil, "admiring a large rectangle of freshly turned earth, black and moist from the spring rain" (Wilson 74). He says, "Just look at this soil" (Wilson 74), he was so proud for the good conditioned soil he kept nurturing for years they way his father has taught him,

> This has got to be some of the best in the country. My daddy worked hard to keep these fields in good shape. He made sure Eddie and me spread plenty of manure. He used to watch us work, and whenever we slowed down he'd say, 'The nation that destroys its soil destroys itself.' Franklin D. Roosevelt (Wilson 74)

7.2 The nature of soil:

Rosalie, during the conversation gets distracted by the smell of the freshly turned soil, "distracted by the fertile smell of the earthworms, old manure, and damp soil." (Wilson 74). She starts to get the ideas for planting her seeds by finding a good plot of the farm, but she has never been a gardener but convinces herself as, "seeds were seeds, whether they come from the pumpkin or fell from a tree. Seeds need soil and water and sun" (Wilson 74). And she also remembers the words from her father, "I thought of something my father used to say: that we watch and we learn from the trees and plants around us." (Wilson 74).

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The importance of seeds, food everything starts in the early life of Rosalie. The young Rosalie was actually met with the Sioux Indian War of 1862, in the state of Minnesota, she remembers, "the war has changed everything, reshaped my world into a shifting mass of confusion and death and hunger" (Wilson 83). The war can change many things, one of it was the quality of food, Rosalie's Mother, she was afraid about the ideas behind the food they consumed, which had the safety concern of present and the anxiety for the future,

> But she was afraid of the food they handed out. She worried about what would happen when the women no longer knew where to find medicines, when the men gave up hunting, if they began to drink instead. She said our food was sacred because it made life. "This food has no spirit" (Wilson 85)

The seeds that prevail in the present time farming systems, they must have undergone various changes and met with many sacrifices, and they were saved by our ancestors as one of the valuable things, likewise even undergoing the dire conditions of death and hunger, Rosalie's mother saves those seeds, even when the soldiers take every valuable things from them, they had the responsibilities to safe those seeds to the future generation,

> That night, Ina showed me how to sew rows of seeds into our skirts, along the edge of our blanket…My mother was afraid the soldiers would take everything of value left to us. She knew too, that if the food ran out, these seeds would have to be hidden from her own people, who would be desperate to feed their children. She had to keep enough seeds for planting. (Wilson 87)

8. THE DIFFERENCE IN TRADITIONAL AND MODERN FARMING SYSTEMS

The intervention of cooperates into the farming systems as they sell us both the hybrid seeds and also the pesticides and herbicides, "Nowadays these big companies are the ones selling us the pesticides and herbicides that you use on your fields" (Wilson 116). Gaby works out like a warrior and a protector insisting Rosalie, "You may be living on a farm, Rosie, but you still have to think like a Dakhota. You can't sit back and let others poison the river or the land or around with our seeds. Think about the sacrifices our ancestors made. You have to make a choice" (Wilson 115). Rosalie was filled with passion and remembers the true knowledge her father had taught her about the woods and now the responsibilities she carried forward after Gaby's thoughts.

The strong seed of thought about her responsibility in safeguarding those traditional seeds is acclaimed through one fire accident. One day a fire broke out in Rosalie home, everyone was panicking to come out of it holding their needful things that they wanted to safeguard it from the fire. Rosalie actually forgot about her son Tommy, but held the boxes of seeds with her. When she explained, "I just knew I had to get those seeds out, no matter what. I never stopped to check that Tommy was truly safe. All I thought about was the fire, and then those seeds" (Wilson 121).

The ecological thought and the co-existence exhibited as, "*The ecological thought* is the thinking of interconnectedness." (Morton, 16), Rosalie delivers to her son, a story of mice and the Dakota people, a joke that prevailed between the indigenous people, while teaching him in the garden how the delicate vine creepers held to the long plant for their survival. And both of them were collecting the hog peanut. She says, "In the fall, mice gather these beans for their winter food. My father, told me that Dakota women used to always bring some corn to trade for beans with the little mouse" (Wilson 122). She teaches the food prosperity and the sharing kindness through food that they even didn't want the mouse children to starve, "So the mouse children would not starve. No one wants their children to go hungry. That's why we always share our food." (Wilson 122). Tommy is taught with the co-existence as Rosalie teaches him,

> *We all depend on each other to survive. The plants we gather give their lives; the deer gives its life. Someday we will give ours, too. You have to be respectful, knowing that a plant's or*

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animal's life is a gift that allows us to live. You never take more than what you need. (Wilson 123)

Rosalie herself finds the nature as her healer and most importantly in teaching her son she also remembers her father's teaching like the sacrifice a mother tree held in it to help its sapling grow well,

I needed the comfort of plants around me, the language of their mute endurance, their ability to survive and thrive and adapt. My father had once pointed out a chokecherry tree that had dropped most of its leaves, while a young tree nearby was thriving. The mother tree had chosen to sacrifice its own health for its offspring, sending its share of nutrients to help the other tree battle a fungus. The young tree recovered and over time, the mother tree also regrew its leaves

The difficulties of farmers are used by the cooperate companies like Mangenta, to bring the initiatives in the means of producing high yields, in order to survive financially, farmers take the dept and sign the contracts with the Mangenta only to us their seeds, not any other traditional varieties. The one of the difficulties can be given as sending their children to school, to make them study by raising money or selling their supporting vehicles, "For families accustomed to barely getting by in years when the harvest was hit by disease or drought, suddenly there would be hope that they could replace a tractor or put something aside for their kids schooling" (WILSON154). When Judith gives the detailed account that sometimes women had the jobs outside the farm to meet the errands of the home during winter,

These families were not only thirsty for rain; they were hungry for life that held a bit more ease, a lessening of the anxiety that gripped each one of them from seed planting until the safe delivery of the harvest to the grain elevator. Most of them-if they'd been farming long enough – knew what it meant lie awake at night worried about how to pay the mortgage and the loans on their equipment. A lot of the wives, like myself, had jobs in town to help make ends meet. Money that meant we could survive the long winters (Wilson 154)

George and Judith who had a beautiful farm once, because of Genetically Modified seeds came into play, George refusal in using the seeds after signing the contract got him into the lawsuit with the Mangenta, the company had strong base of lawyers working for it, and a layman like George or any simple farmer can't fight justice with them. Every other farmers in the area gathered to witness, "the dismantling of their farm" (Wilson 174). George lost in lawsuit and lost everything he had, but he still had the determination in saying, "George swore to everyone who would listen that he would grow only the "real" heirloom corn from then on, using organic methods, a plan that left the other farmers shaking their heads" (Wilson 175). Even John could agree what George said, "…it's too much risk growing GMO corn so close to his own fields." (Wilson 175). And Rosalie feels the auction looked like a funeral, she says, "the auction had the feeling of a funeral, of an unspoken loss that nonetheless had to be dealt with. Life on a farm was challenging, and not everyone made it." (Wilson 176). Now the real problem occurs in the farm, George spills out the reality,

You've let accountants and lawyers tell you how to run your farms, how to treat your animals. Now we've got chickens that can't walk without breaking a leg. We've got soil that can't grow anything without its daily dose of chemicals. And look what we've done to our river. (Wilson 177).

9. CONCLUSION

Rosalie becomes a lifesaver for the farmers, when she grows the traditional variety of the corn seeds that she receives from her aunt, Darlene who she finds as her only family apart from her son. She helps farmers around to survive the disaster through her seeds. This variety of corn kept the nutrient supply to consumers, which in turn kept a balanced diet and good physical health of the people. In the work, "*The Living Soil Handbook*", the author says "It's about leaving behind the forceful –agriculture mindset and enabling the soil to do what it naturally wants by once again engaging in regeneration"

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(Frost 14). Considering, "the threat of climate change and biodiversity loss, ongoing disempowering dynamics, widespread challenge to food and nutrient security" (Anderson, et al, 21), the viable path to the change is concentrating on improving the soil health, "the most viable pathway to Agroecological transformation for sustainable and just food systems" (Anderson, et al, 21). Agroecology becomes the only solution to the modern way of agriculture which is highly resource consuming, nutritionally imbalance, destroying the healthy soil and the human health. The way of agroecology can maintain the ecological balance and ensure the nutritional rich foods and healthy survival of humans on earth with the better co-existence with the nature.

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DIASPORIC FEMINISM AND CULTURAL BOUNDARIES IN KIRAN DESAI NARRATIVES

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ABSTRACT:
The research aims to explore the Diasporic feminism and cultural boundaries in Kiran Desai's narratives. The primary objective is to identify, analyze, represent and revitalize how Desai presents the women's experiences through gender marginalization, root-shifting, life in exile and ethno-cultural identity, cultural displacement and hybridity. The novelty of this research lies in its representation of feminist epistemology, intervention, resistance, intersection of the cultural and transnational experiences. The primary research method adopted for this study is qualitative textual analysis. To validate arguments, key parameters are covered, which include but are not limited to power relations, cultural conflict, patriarchal constraints and other interrelated parameters. The research is an answer to the growing need for feminist interpretation in Desai's work, with a focus on the cross-cultural and diasporic interactions. The time period of this research focuses on the feminist voices across borders or feminism within transcultural contexts, along with the postcolonial settings as reflected in her work. Analytical methods include postcolonial diasporic analysis and feminist literary criticism. The study is an attempt to define and redefine the struggle of women and how it shapes and reshapes the discussions on globalization and gender. The research outcome makes it more visible that Desai's narratives present how to negotiate inner conflicts and cultural norms imposed and traditions inherited while endeavoring for Automator or personal meaning in socio-cultural landscapes.

KEYWORDS: ***Diasporic Feminism, Cultural Boundaries, Gender Marginalization, Transcultural Identity, Postcolonial Analysis***

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1. INTRODUCTION

Desai, as a radical feminist writer and cultural depicter, is known to bring freshness to the concept of feminist diaspora and cultural belonging with her engaging storytelling. No doubt, all three works by Desai, such as Hullabaloo in the Guava Orchard (1998), The Inheritance of Loss (2006), and The Loneliness of Sonia and Sunny (2025), are known to express varied levels of feminism, cultural sensibilities, and challenges. Desai, with her narratives, subtly portrays women's gendered experiences of displacement, identity negotiation, and cultural conflict, which align with diasporic feminism.

The study is more focused on how feminism, along with cultural hybridity and identity, converge and unify to deliver a more holistic and unique diasporic experience. It presents diasporic feminism as a creative, living, growing thing, a self-reflective process more relevant in today's fast-evolving era of cultural and hyphenated identities or transcultural negotiations. It makes an attempt to explore the evolving vision of diasporic feminism through textual analysis of her works. It adopts a more modern, interdisciplinary theoretical framework, drawing from diaspora studies, translingual and post-colonial theories. Closely navigating and examining the emotional terrains, this research actively contributes to the much broader understanding of the diasporic literature, contemporary discourse in cultural studies, and effectively bridges the translingual and diasporic studies. The core argument is that her works transcend the notions of belonging, cultural, and translingualism. Her literary oeuvre clearly defines, refines, and sketches multidimensional diasporic and feminist identities, along with the cultural displacements.

Over the past few decades, diasporic feminism as a writing tool has undergone a significant transformation. There are so many writers whose works represent various themes from emotional to cultural displacements, cultural schizophrenia, deterritorialization, intergenerational trauma, bicultural identity, or cultural resistance within the diaspora world. Feminist diaspora writing is more centered on the concepts of feminist belongings, quest for cultural identity, nostalgia, exile, and other interrelated and correlated themes evolving due to physical migration or emotional migration. With globalization impacting the lives of the people, translational flows of ideas and, particularly, people generating those ideas are known to be more intensified. The diasporic writing has emerged as one of the complex and hybrid figures. Though many writers are known to promote diasporic writing through their works, it is Kiran Desai who has been credited with offering a more unique, impactful, and fast-evolving vision of feminist diaspora and diasporic culture that is well beyond feminist selfhood, physical migration, transgenerational memory, or imagined homeland.

Her narrations engage more deeply with the unhomed existence, the philosophical condition of women in exile, women's freedom, belonging and autonomy. This paper flawlessly situates Desai's work within diasporic feminism and analyzes how cultural boundaries influence female subjectivity. Some of the scholars, such as Avtar Brah, Homi Bhabha, Chandra Talpade Mohanty, Gayatri Chakravorty Spivak, and Steven Kellman, offer insights into discourse on diaspora and feminism.

Feminist Diaspora Theory examines a series of events, scenarios, life episodes, or experiences of a woman or a community that lives away from their homeland or culture. It provides insights into collective feminist identity or a broader community of feminist voices across cultures. This theory delves more into the political, emotional, psychological, cultural, sociocultural, and linguistic consequences of living in a foreign land or across national borders. Broadly speaking, diaspora is just a term that denotes only physical movement, but it is a more living and growing cultural condition, a psychological state of mind, a cultural phenomenon that is marked by a sense of loss, adaptation, memory, belonging, nostalgia, alienation, grief, silence, rootlessness, or hybrid identity. It may cover various other themes such as generalist conflict, emotional and social challenges an individual faces by being in a foreign country, and ultimately, the transnational mobility.

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2. Significance & Scope of the Study

The research is focused on diasporic feminism more as a cultural inquiry, and it effectively contributes to feminist literary criticism and inquiries into Kiran Desai's authorial role, which is interlaced with the quest of her own culture and identity. The scope of the research is limited to selected narratives of Kiran Desai, analyzed within postcolonial and diasporic feminist frameworks. The study remains literary and theoretical in nature, without extending into sociological fieldwork.

3. Objectives of the Research

- To identify and analyze diasporic feminism in Kiran Desai's works.
- To examine how cultural boundaries transform female identity, hybridity and patriarchy.
- To contribute to feminist interpretations of contemporary diasporic literature

4. Hypothesis & Research Methodology

Hypothesis

The study is based on the hypothesis that Kiran Desai's narratives represent diasporic and feminist voices, silent resistance, cultural hybridity, and patriarchal boundaries through implicit resistance or quiet negotiation rather than overt defiance or radical opposition.

Research Methodology

A qualitative methodology grounded in textual analysis is adopted for this research. Primary texts are analyzed from a view of feminism and cultural negotiations. Secondary sources include scholarly articles, critical essays, and theoretical texts related to diaspora and feminism.

5. Literature Review

- **Gendered Diasporic Identities/Transcultural Boundaries**

Feminist diasporic writing is known to be evolving with Indian female voices demanding attention, and with the expression of postcolonial migration, or contemporary globalization (Das, 2021). No doubt, literature emerging from typical diasporic scenarios entails a rich tapestry of expressions, defines dislocation, belonging, and negotiating identity in multiple ways. Agnihotri (2025) explained that feminist diasporic narratives will have a much stronger polyphonic structure. The writers, children of immigrants or immigrants themselves, present multiple perspectives of life in a foreign country, depicting the ways identities are mediated through the impact of a new culture or generational differences.

Desai is one of the prominent writers in the literary landscape, and her work masterfully presents the evolution of womenism and cultural belongings. It effectively traverses women's identity, emotional landscape, and cultural reinvention. Diaspora or identity theory forms the basis of works such as Hullabaloo in the Guava Orchard, The Inheritance of Loss, and The Loneliness of Sonia and Sunny. This review of Desai's writings perfectly aligns with the broader context of the diasporic and feminist literature, with due concentration on some of the prominent themes that her work presents, such as generational shifts, emotional exile, or cultural hybridity.

- **Critics on Feminism and In-Between Cultural Spaces**

Critics generally agree that her narratives do not actually project feminism outright. The representation of feminism in her work is not through a conventional sense of activism. There is no political rebellion. Rather, her work defines embedded feminism shaped by the realities. Rampur and Venkateswaran (2017) argue that her female characters tend to endure cultural constraints more quietly. Ahmad and Gautam (2021) explain that female voices are subdued, and it could be an impact of living in loneliness or living in silence. In the views of Gogul and Shanantha, her work exposes patriarchy as a more common issue restricting freedom. According to Saini (2016), feminism in Desai's narratives is psychological rather than political. Female characters tend to negotiate their own identity through self-

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reflection, adaptation to their surroundings, and emotional endurance. Desai's work is characterized by psychological depth and emotional minimalism. Researchers such as Kumari and Bachchan have placed Desai among the top writers with a good understanding of feminist diaspora and are praised for effectively internalizing the emerging feminist conflicts. Boehmer (2015) explained that Desai's female characters are more silent and they do not often revolt. They bear the pain and do not talk about it. They are introverts. A feminist scholar in Desai's work is in the form of patriarchal constraints (Mohanty, 2003). Spivak (1998) showcased how portrayal of women in Desai's narratives coexists with the postcolonial feminism that centers on gendered oppression within cultural frameworks.

- **Women, Migration, Cultural Power and Globalization in Desai's Work**

Migration has been one of the core forces that shape human history. Diaspora as a phenomenon in close context with the Indian women living in a foreign land has been a fertile ground to study, define, and analyze women's fiction. Kiran Desai is best regarded for her representation of women in a foreign land. Her fiction has garnered enough attention from the researchers and scholars with an interest in diasporic writing and feminism. Her fiction is known for its layered portrayal of key issues connected to feminism, migration, postcolonial legacies, memory, loss, solitude, loneliness, etc. Diaspora is a living, growing thing that shows human life and human experiences in a non-native country. But the study of diasporic literature from a feminist point of view is limited. Kiran Desai's narratives flawlessly articulate the lives of women. Her work offers much greater insights into gendered experiences, with due attention on caste, class, race, economic conditions, transnational perspectives and other interconnected perspectives.

The portrayal of cultural boundaries, cultural negotiations, and gendered subjects is predominant in her writings. Rather than showing diasporic identities as synonymous with hybridity, Desai's work attempted to showcase hybridity as fraught and it is seen in a continual state of transformation, the changes emerging from the gendered violence and inequalities. Another dimension of her diasporic writing is that her characters tend to combat or retaliate against themselves. They introspect and look for sense in their decisions. They also refuse reductive opposition. Critical analysis of Desai's work shows that her work is beyond the commonality of migration and globalization. Researchers tend to read The Inheritance of Loss as a postcolonial literature work that delivers.

- **Postcolonial Feminist Perspectives in Desai's Work**

Sahaja (2024) describes colonialism and power in her work and how characters become stronger with day-to-day struggle in a society that is transformed by colonial influences and indigenous cultures. Land, language, labour, and knowledge form colonial settings. Though oppression, distortion or silence also forms a part of her narrative, it is feminism that is structured more strongly. Desais' work explores postcolonial inheritance, migration and globalization but there is a layer of feminism too that is often misunderstood and is not fully studied too. Sindhu argues that Desai, through her feminist characters, challenges eurocentric views, giving voice to historically marginalized women living far away from their motherland or their communities. Furthermore, her style of

According to Borgohain and Ammari (2022) Indian women in diasporic literature symbolise the struggle. The struggle for existence, the struggle for identity revival and cultural adoption. Desai smartly depicted this struggle of an Indian woman in patriarchal society, and her work provides a significant contribution towards understanding where the woman stands in a society that continuously changes (Raina, 2018).

6. Feminism and Cultural Constraints in Desai's Narratives

Though Hullabaloo in the Guava Orchard is often presented as both comedic and satirical, it comprises more astute observations of life and gender roles. Cultural boundaries are presented through a small town, a provincial town that is labelled as a microworld, a place where modernity and tradition overlap and such an environment affects the life of the women too. Families or communities living in the town

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have established norms, and they want to follow the norms to continue to preserve them. or feel it essential to follow to carry them forward. Desai artistically uses the domestic and public places in this work and flawlessly maps out the restrictions levied on women. Different characters that a woman plays, like mother, daughter, wife, are culturally and socio-politically confined to only households. Their social roles are neglected.

The comic portrayal of the novel also permits distance and irony. Desai uses these literary tools to reveal hypocrisy. The laughter is well concealed within the parameters of the communal self-understanding. Through humour Desai painted the marginalized voices more effectively. It is significant to note that the orchard itself acts as a boundary. It is both transformative and liminal. Geographical marginality is well expressed through destabilization and entrenchment, various stages the characters go through. The norms or the boundaries change with the changes in gender.

Similarly, The Inheritance of Loss reveals gendered dispossession. It depicts transnational lives with due concentration on the woman's life. The Inheritance of Loss is often treated as Desai's most powerful novel. It is described as politically ambitious and it is set in the mid-1980s in two different locations the foothills of the Himalayas and in New York City. Earlier, her work The Inheritance of Loss is construed to be more focused on the cultural inheritance, legal and psychological inheritance. But deeper analysis reveals a different aspect of her writing too. That is diaspora feminism. It is abundant in presentation of the female voices, female dominance, thinking, action and perseverance.

The novel interweaves the lives of the characters caught between global economics and local historical, local culture and foreign culture. It is more focused on the postcolonial legacies, migration, cosmopolitanism, and it certainly creates a rich terrain for feminisms from the diasporic angle and analysis.

It is noteworthy to mention here that The Inheritance of Loss is differentiated along feminist values, gendered issues, and domestic labour. While male characters are described as free with free thinking with the opportunities to explore, pursue education, pursue career abroad whereas female characters are restricted from chasing their dreams, or venturing into metropolitan hubs. Female characters face challenges at every stage of their lives in various forms such as domestic labour, marriage, finding love, retaining love, retaining culture, protecting family values, caregiving, mobility, and dependence. The novel shows migration as exploitation too and also underscores the heterogeneity of the feminist experiences abroad.

Desai's depiction of the intergenerational trauma, memory, madness, and maternal figures defines gendered inheritance, too. Characters embody contradictory roles. For instance, characters are transmitters of tradition and are caretakers of the traditions too. Characters suffer silently. They want to protest or break the chains that they are bonded with, but they do not. They do not want to move out of their boundaries as set by the families. They want to rebel. They are inwardly cautious of the consequences of moving out of the boundaries. Therefore, tend to be within the cultural boundaries. Desai's characters both love and detest traditional life. As Kiran Desai is a migrant writer, she perfectly portrayed this cultural agony through this novel. In one way, this novel also describes her longing for her homeland. They dare to challenge globalization in a distant land. Feminism in The Loneliness of Sonia and Sunny is also more evident. The narrator effectively extends feminist concerns into a contemporary globalized setting. It is more subtle and relational. Sonia’s isolation is not merely personal but structurally produced. She is seen navigating expectations around relational maintenance. Loneliness is described as invisible, and this also signifies that woman are expected to absorb pain. She expresses it, but only to a certain extent.

Women, no doubt, occupy a more important place in Desai's fiction. In Hullabaloo in the Guava Orchard or The Inheritance of Loss, female characters go through different patriarchal stages, and their lives are shaped by globalization, clinical legacies. They exhibit moments of emotional complexity, eccentricities, resistance, and silence. Desai presented them not as a unified symbol of empowerment or

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oppression, sadness or happiness, freedom or captivity. They are also heterogeneous subjects negotiating power within transnational spaces and social spaces.

Three interrelated concerns are explored, such as transgression, globalization, and domestic confinement.

6.1 Freedom v/s Captivity

Domestic space in Desai's novels functions both as a site of oppression. and shelter. Women are caregivers. Women are torchbearers. They act as a guide, and they also reflect the traditional gender expectations when it comes to Indian communities. women such as Sampath's grandmother in the novel, Hullabaloo in the Guava Orchard is rooted in social surveillance, family responsibilities, family honor, and obedience. The older women enforce patriarchal values, and they tend to guide younger women and instruct how to behave or how not to behave. This is typical of Indian culture, and patriarchy is produced or enforced by women on women. This is domestic confinement, but it emerges into different forms of confinement too, including but not just limited to confinement of thinking, confinement of desires, etc., and this further becomes a mechanism that propels the social norms to be transmitted and internalize well.

In The Inheritance of Loss, domestic spaces are supercharged psychologically. Home is a place of safety, but when it turns into a place of terror, then naturally, life is beset with continuous struggle. Nimi's marriage to Jemubhai Patel clearly describes how a place expected to be a place of safety transformed into a place of agony and trial. Nimi's life exemplifies how patriarchal authority can be dangerous, and how, if it is intensified further by colonial masculinity, it could bring psychological disturbance and tyranny.

Nimi's confinement to a single place reflects the silencing of women and how force is often employed to restrict women from leading their own lives. Though Nimi's suffering remains unacknowledged by the other characters across society and the family.

6.2 Desire and Fear of Transgression

Furthermore, female desire and fear of transgression are portrayed side-by-side. In the case of Kulfi Chawla, her desires defy her image of a wife and a mother. Although she doesn't articulate her feelings through her actions, her desires remain within her, and she continues to live her life with her husband, raise children and live in society as a woman who marks a rejection of socially acceptable femininity. Her retreat into the orchard defines her escape from social legibility or domestic control. But in The Inheritance of Loss, desire is marked by emotional risk and anxiety. Sai is seen as more skeptical of her own moves. Her romantic relationship shows her vulnerabilities as a woman of desire who is moving through unequal power relations.

6.3 Loss of Feminist Voices: Irreparable Damage

Nimi, the wife of Jemubhai Patel, is considered by many critics as one of the most tragic female figures in Desai's narratives. She is silenced within marriage. She loses her voice. She loses her identity and dignity. She is subjected to emotional abuse &Physically tortured too. Her character is reduced to a shadowy presence. Male dominance is the prevailing issue in this work. Jemubhai's colonial humiliation converts into domestic cruelty. Nimi's suffering shows how colonial masculinity can destroy women's lives. Her loss is irreparable.

6.4 Loss of Belonging: Pragmatic Survival

In Inheritance of Loss, Sai is educated with desires to lead a better life. She is modern. She is English-speaking, but she is still alienated. She finds it difficult to adjust to societal expectations and cultural changes. Loss of cultural rootedness, romantic fulfilment, and emotional security are portrayed through her character. Sai fails to belong fully either to Indian tradition or global modernity. Her relationship ends in disappointment, leaving her emotionally isolated.

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7. DISCUSSION/RESULTS

The findings suggest that diasporic feminism in Desai's narratives manifests through endurance, reflective selfhood, silence, evolving self-consciousness, or emotional perseverance. Cultural limitations work dually as transformative spaces. Characters are seen struggling to create possibilities for change, facilitating identity formation through inward resilience rather than external defiance. Cultural boundaries, as paradoxical forces, act as a space of transformation and confinement, too.

Table 1: Feminist Consciousness in Kiran Desai's Work

Desai's Narrative	Feminism	Resistance	Interpretation
Hullabaloo in the Guava Orchard	Subordinate female positioning or Silenced female subjectivity	Silent resilience	Feminism appears through absence, highlighting patriarchal exclusion
The Inheritance of Loss	Reflective feminism or Existential feminism	Silence and conformity, Internal endurance and negotiation	Feminism is subtle, psychological, and shaped by diaspora
The Loneliness of Sonia and Sunny	Limited female visibility, Underrepresented womanhood		Feminism is limited but has a far greater impact

Feminist consciousness is more visible in Desai's work and it is interpreted to be non-confrontational or understated. Her work stresses more on emotional resilience, women's internal struggles, her silence, and endurance, indicating a more realistic model of feminism that is rooted in everyday survival.

Table 2: Cultural Consciousness in Kiran Desai's Narratives

Desai's Narrative	Cultural Boundaries	Interpretation
Hullabaloo in the Guava Orchard	Patriarchal family structure / Limited autonomy	Partial self-awareness, Emotional endurance
The Inheritance of Loss	Traditional gender roles / Restricted self-expression	Psychological survival, Cultural in-betweenness and emotional alienation
The Loneliness of Sonia and Sunny	Limited female visibility, Underrepresented womanhood	Absence of cultural ties, cultural transformation. New identity formation, identity, liberation

The analysis reveals that Desai's narrative is embedded with the cultural boundaries. Characters tend to compromise with their surroundings, make changes in their lives, or assume changes as a way of living. Cultural negotiations, adaptations and confrontations exist in multiple forms. Feminist resistance, along with the loss of one's own cultural identity exist in non-visible forms. Silence, voice, migration, female suffering, globalization, colonialism, and masculinity in Desai's novels are deeply gendered processes. They are Desai's most powerful feminist interventions. Kiran Desai's fictional world represents women not as idealised heroines nor passive victims. Female characters are more complex. Their lives transform with acceptance and rejection of the social constraints, cultural values, and social norms and expectations. Desai perfectly exposed the gendered dimensions through desire, endurance, silence, and domestic violence. By situating resilience and suffering through her female characters, Desai aims to propel readers to reconsider assumptions of emancipation, progress and mobility. The result also points out the fact that a society can't flourish until it pays attention to women's voices.

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8. LIMITATIONS & FUTURE SCOPE

The study is limited to literary texts and theoretical analysis; This study doesn't include or focus on any kind of empirical data or reader-response studies. Future research may focus more on comparative feminist literature, feminist voices, and narratives from different diasporic writers. And of course, interdisciplinary approaches that may incorporate other interconnected themes, such as gender studies and social studies.

9. CONCLUSION

Kiran Desai's narratives clearly provide insights into diasporic feminism and cultural boundaries that exist in the form of complex negotiations of gender, identity and voices. Characters evolve with time and change of place. They grow more silent or revolt with subtle energy, accept or challenge traditional boundaries. Through self-realization and psychological endurance, diasporic feminism thus grows as a philosophical condition in Desai's narratives and it continues to transform by cultural hybridity and cultural displacement. Her work challenges more dominant feminist paradigms visible in the form of limited freedom. Her narrative truly offers a critical lens for understanding feminism and cultural negotiations within transcultural and postcolonial environments. Thus, this research effectively reinforces how Kiran Desai's narratives contribute to diasporic feminism and how cultural boundaries create inequalities and ambiguities that lead to gendered issues.

Her work describes facile oppositions but at the same time focuses on ways to resist such oppositions. No doubt, her fictional world is more significant and underscores the need to analyze globalization, culture, migration, and language, with attention to the feminist theories and experiences too. Her fiction doesn't only offer a prescriptive solution to deal with the feminist or gendered issues that evolve or threaten societal progress. Rather, her work symbolizes lives of freedom, reimagining a world where women are free to make their choices, lead and make an impact.

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THE ISSUES OF COMPLEXITY, PREDICTABILITY, AND PROBABILITY IN THE CALCUTTA CHROMOSOME: A RE-READING

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ABSTRACT:
Amitav Ghosh's The Calcutta Chromosome (1995) occupies a singular position within contemporary Indian English fiction for its refusal to conform to generic, epistemological, or narrative expectations. Straddling the domains of historical fiction, speculative science, and philosophical inquiry, the novel interrogates the foundations upon which modern scientific knowledge is built. This paper offers a re-reading of The Calcutta Chromosome through the interrelated concepts of complexity, predictability, and probability—ideas central to both scientific discourse and postmodern literary thought. It argues that Ghosh systematically unsettles linear causality, empirical certainty, and deterministic logic through a fragmented narrative form and competing knowledge systems. By juxtaposing colonial science with subaltern epistemologies grounded in silence, intuition, and ritual, the novel exposes the limits of rationalist paradigms. In blurring the boundary between the probable and the possible, The Calcutta Chromosome proposes an alternative vision of knowledge—one that resists transparency, embraces uncertainty, and foregrounds the ethical and political significance of the unknowable.

KEYWORDS: ***Complexity and Nonlinearity, Postcolonial Epistemology, Scientific Uncertainty, Narrative Fragmentation, Silence and Subaltern Knowledge***

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1. INTRODUCTION

The Calcutta Chromosome is widely regarded as one of Amitav Ghosh's most challenging and unconventional novels. From the outset, it resists straightforward classification, drawing simultaneously on science fiction, historical reconstruction, detective fiction, and metaphysical speculation. The narrative moves across temporal and spatial registers—from colonial Calcutta to a technologically saturated future—creating a textual landscape in which continuity is constantly disrupted.

Critical discussions of the novel have largely focused on its postcolonial reimagining of scientific history, particularly its revisionist engagement with Ronald Ross's celebrated discovery of the malaria parasite's transmission. While such readings remain indispensable, they often overlook the novel's deeper structural investment in uncertainty itself. This paper suggests that complexity, unpredictability, and probability are not simply themes within the narrative; they are the very principles that govern its form, logic, and epistemological commitments.

Rather than offering an alternative history that merely corrects colonial omissions, Ghosh constructs a narrative world in which knowledge is fragmented, dispersed, and frequently inaccessible. In doing so, The Calcutta Chromosome compels readers to rethink dominant assumptions about how knowledge is produced, validated, and transmitted.

2. COMPLEXITY AND THE ARCHITECTURE OF ENTANGLED KNOWLEDGE

I. Narrative Complexity and Non-Linear Temporality

The narrative structure of The Calcutta Chromosome closely resembles what complexity theory describes as a non-linear system—one in which meaning emerges through interaction rather than sequence. The novel unfolds through discontinuous episodes involving Antar, a data analyst in a future New York; Murugan, a restless and obsessive researcher; and the historical figure of Ronald Ross in colonial India. These narrative strands do not converge neatly. Instead, they intersect obliquely, leaving gaps, overlaps, and unresolved tensions.

This fragmentation resists the comfort of linear progression. As Paul Cilliers observes, a complex system loses its essence when reduced to a single explanatory framework (Cilliers, 1998). Ghosh's narrative operates on precisely this principle. Each storyline remains partial and provisional, acquiring significance only through its relation to others.

Characters such as Lakhan, also known as Lutchman, exemplify this complexity. Appearing across different temporal frames yet never fully explained, he destabilises conventional expectations of character development. His opacity is not a narrative flaw but a deliberate strategy, reinforcing the novel's refusal to translate complexity into coherence.

II. Competing Epistemologies: Colonial Science and Subaltern Knowledge

At the heart of the novel lies a confrontation between two fundamentally different modes of knowing. Ronald Ross embodies the Enlightenment ideal of empirical science—linear, experimental, and document-driven. Yet Ghosh presents Ross as limited by his methodological assumptions, unable to perceive the forces operating beyond his rational field of vision.

In contrast, figures such as Mangala and Lutchman participate in a radically different epistemological order. Their knowledge is transmitted through embodied practice, ritual, and silence rather than written records. The speculative idea of chromosomal transference—where consciousness or memory migrates across bodies—functions as a metaphor for this alternative science, one that does not separate the material from the metaphysical.

This tension closely aligns with Boaventura de Sousa Santos's argument that Western epistemology systematically marginalises other ways of knowing (Santos, 2014). Ghosh's novel does not merely recover subaltern knowledge; it insists on its irreducibility to dominant scientific paradigms.

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3. Predictability and the Crisis of Scientific Causality

I. Questioning the Myth of Scientific Certainty

A central provocation of The Calcutta Chromosome lies in its interrogation of scientific predictability. Although Ross's malaria research is historically celebrated as a triumph of Western science, the novel subtly undermines this narrative by suggesting that his success depended on the concealed interventions of Indian assistants.

This narrative revision destabilises the Enlightenment faith in causal certainty. Scientific discovery, Ghosh implies, is neither neutral nor autonomous; it is embedded within power relations. Edward Said's critique of Western knowledge as complicit in colonial domination is particularly relevant here (Said, 1978). Prediction, in this context, becomes not merely a scientific tool but a political one.

By allowing Ross to believe in his individual achievement while withholding the deeper truth, the subaltern network transforms invisibility into a strategy of resistance.

II. Temporal Disruption and the Instability of Identity

Time in The Calcutta Chromosome does not behave predictably. Antar's present is haunted by colonial histories, while Murugan's investigations collapse temporal distances altogether. More radically, identity itself becomes unstable, as characters appear to transcend bodily and temporal boundaries through chromosomal transference.

These disruptions resonate with Ilya Prigogine's conception of time in complex systems, where irreversibility and unpredictability are fundamental rather than anomalous (Prigogine & Stengers, 1984). Ghosh's narrative suggests that what appears chaotic may in fact follow a logic that resists human comprehension.

4. Probability, Speculation, and the Threshold of Plausability

I. Speculative Science and Narrative Credibility

The idea of the "Calcutta chromosome" occupies an ambiguous space between science and speculation. While biologically implausible, it is embedded within a meticulously researched historical and scientific context. This grounding allows Ghosh to explore speculative probability without abandoning narrative credibility.

Rather than asserting scientific truth, the novel explores what N. Katherine Hayles describes as the liminal zone where fiction tests the boundaries of scientific plausibility (Hayles, 1999). The chromosomal theory becomes a conceptual device for imagining alternative futures of knowledge.

II. Coincidence, Pattern, and Hidden Order

Coincidence plays a significant role in the novel. Encounters appear accidental, objects recur mysteriously, and connections span decades. Yet these coincidences are not random; they hint at an underlying pattern that remains partially concealed.

This narrative logic echoes the notion of "strange attractors" in chaos theory—structures that generate order without predictability. Probability in The Calcutta Chromosome thus acquires cultural and metaphysical dimensions, moving beyond statistical calculation.

5. Silence, Absence, and Epistemological Resistence

I. Silence as Knowledge Practice

Silence in the novel functions as an active epistemological strategy rather than a narrative omission. Mangala's authority derives precisely from her refusal to speak or explain. Her silence counters what Michel Foucault describes as the modern compulsion toward total knowledge and visibility (Foucault, 1972).

In Ghosh's narrative, articulation threatens to destroy what it seeks to preserve. Knowledge survives through concealment, suggesting an ethics that values restraint over revelation.

II. Absence and the Limits of Proof

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Murugan's failure to conclusively establish the chromosomal theory underscores the limits of evidence-based reasoning. His obsessive documentation yields fragments rather than certainty, ultimately leading to his disappearance.

This resonates with Veena Das's concept of "negative knowledge"—forms of understanding constituted through absence and silence rather than verification (Das, 2007). Ghosh privileges this negative space as a site of enduring meaning.

6. Technology, Surveillance, Failure Of Prediction & Complexity As Narrative Ethics

Antar's technologically advanced world appears designed to eliminate uncertainty. Ava, the artificial intelligence system he works with, epitomises algorithmic rationality. Yet Ava's inability to resolve Murugan's disappearance exposes the limits of predictive systems.

Ghosh anticipates contemporary anxieties surrounding big data and algorithmic governance. The novel suggests that complexity cannot be fully computed, and that technological precision does not guarantee epistemological clarity.

While the text engages with posthuman themes, it resists the idea that technological enhancement represents the inevitable future of humanity. Chromosomal transference, unlike digital immortality, remains embodied, communal, and ritualistic.

- **Refusal of Closure**

The novel's open-ended conclusion denies readers the satisfaction of resolution. This refusal is ethically significant. By withholding closure, Ghosh prevents interpretive domination and insists on the legitimacy of partial knowledge.

- **Reading as Participation**

Reading 'The Calcutta Chromosome' becomes an act of navigating uncertainty. Meaning emerges through engagement rather than mastery, aligning the reader's experience with the novel's epistemological commitments.

- **Postcolonial Complexity And Counter Science**

By embedding uncertainty into its narrative fabric, the novel challenges the colonial aspiration toward total knowledge. Silence, secrecy, and unpredictability become tools of resistance rather than signs of deficiency.As a counter-archive, The Calcutta Chromosome reimagine history from the margins, echoing Dipesh Chakrabarty's call to provincialise European knowledge systems (Chakrabarty, 2000). Beyond counter-history, the novel imagines a counter-science—adaptive, relational, and resilient across time.

7. Conclusion

The Calcutta Chromosome endures as one of Amitav Ghosh's most intellectually provocative works because it resists epistemological closure. Through complexity, unpredictability, and speculative probability, the novel dismantles the certainties of colonial science, Enlightenment rationality, and technological determinism.

Rather than rejecting science, Ghosh interrogates its claims to universality and transparency. Knowledge, the novel suggests, may survive best in fragments, silences, and embodied practices.

In an era dominated by predictive technologies and data-driven certainty, The Calcutta Chromosome offers a powerful reminder that uncertainty can be both ethically necessary and politically liberating. Complexity here is not confusion but critique—and the unknowable is not a failure of knowledge, but its most enduring form.

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ENERGY-AWARE CLUSTERING AND ROUTING MECHANISMS IN WIRELESS SENSOR NETWORKS

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ABSTRACT:
WSNs are made up of many tiny sensor nodes which are powered by battery and are deployed to do surveillance on the physical or environmental state. Ineffective data communication is a significant research problem due to the extreme drop in energy and the lack of computing power. Hierarchical clustering has become one of the most successful approaches in enhancing energy efficiency and increasing the network lifetime. The hierarchical routing suggests that sensor nodes are organized into clusters, whereby, some of the nodes are chosen to serve as cluster heads to collect and transmit data to the base station. This paper has carried out an extensive literature review of energy efficient hierarchical clustering methods in WSNs. The cluster-based and grid-based methods are addressed, their design parameters, classification, pros and cons. Moreover, the open research issues connected to scalability, security, mobility, and integration with new technologies (the Internet of Things (IoT)) are brought to attention. The research will help the researchers to choose the right hierarchical clustering strategies to fit certain application needs.

KEYWORDS: *Wireless Sensor Networks, Energy Efficiency, Hierarchical Routing, Clustering, CH selection Selection, Grid-Based Routing*

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1. INTRODUCTION

Wireless Sensor Networks consist of a range of independent sensor nodes capable of co-existing to observe and report such environmental parameters as temperature, pressure, movement, or humidity [1]. "These nodes are wireless and they relay information gathered to a base station (BS) where the information is processed, and decisions made. WSNs find extensive application across environmental monitoring, healthcare, military surveillance, disaster management, smart cities and automation in industries. Although they are highly applicable, WSNs are highly challenged by the little battery power, processing capability, low memory size and limited bandwidth in communication [2]. The batteries are not usually practicable to change or charge as sensor nodes are frequently placed in the remote or hostile environment. Consequently, the energy efficiency is the most important design goal of WSNs.

Hierarchical routing methods especially that of clustering have been researched to minimize energy use and enhance scalability. The sensor nodes are grouped in hierarchical clustering as groups [3] and a cluster head cluster is assigned with the responsibility of collecting data of the member nodes and sending it to the base station. This method considerably decreases redundant transmissions, and balances use of energy over the network. This paper provides a survey of energy efficient hierarchical clustering in WSNs, both the cluster based and grid-based methods. The paper also classifies the methods that are currently in existence, analyzes their advantages and disadvantages and also explains the future research directions.

2. HIERARCHICAL CLUSTERING IN WIRELESS SENSOR NETWORKS

Hierarchical routing arranges sensor nodes into several levels in order to reduce the cost of communication and energy expenditure. Aggregation and forwarding is done by the chosen nodes, instead of each node transmitting data to the base station itself, which leads to a reduction in the number of transmissions [5].

2.1 Design Goals of Hierarchical Clustering

The primary objectives of hierarchical clustering in WSNs include the following goals **[5], [6]**:

- To minimize overall energy consumption
- To Extend network lifetime
- To Improve scalability for large-scale deployments
- To Reduce communication overhead
- To Enhance data aggregation and load balancing

2.2 Key Parameters in Cluster Formation

The following factors influence the effectiveness of hierarchical clustering **[6]**:

- **Residual Energy:** Nodes with higher remaining energy are preferred to be elected as cluster heads.
- **Distance:** Shorter communication distances reduce transmission energy.
- **Node Density:** Dense areas require careful clustering to avoid congestion.
- **Cluster Size:** Balanced cluster sizes helps to distribute workload evenly.
- **Re-clustering Frequency:** Frequent re-clustering improves energy balance but increases overhead.

The main parameters that are taken into account when forming a cluster are listed in Table 1 below and their effects on the overall performance of the network are shown.

Table 1 : Key Parameters Used in Cluster Formation

Parameter	Description	Impact on Network Performance
Residual Energy	Remaining battery power of node	Prevents early CH failure
Distance	Node-to-CH and CH-to-BS distance	Reduces transmission energy
Node Density	Number of nodes in an area	Affects cluster load
Cluster Size	Nodes per cluster	Influences CH workload

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Re-clustering Rate	Frequency of CH reselection	Trade-off between balance and overhead
Node Location	Position relative to cluster center	Improves communication efficiency

3. TAXONOMY OF HIERARCHICAL CLUSTERING APPROACHES

Hierarchical clustering techniques can be classified based on the following criteria **[7]**:

3.1 Homogeneous vs. Heterogeneous Networks

- **Homogeneous Networks:** All sensor nodes have identical hardware and energy capacity. Any node can become a cluster head **[7]**.
- **Heterogeneous Networks:** All nodes have different capabilities, and more powerful nodes are typically elected as cluster heads to improve efficiency [8].

3.2 Centralized vs. Distributed Algorithms

- **Centralized Approaches:** The base station controls cluster formation and CH selection using global network information [9].
- **Distributed Approaches:** Nodes make local decisions based on neighbourhood information, improving scalability and fault tolerance.
- **Hybrid Approaches:** Combine features of both centralized and distributed schemes.

3.3 Static vs. Dynamic Clustering

- **Static Clustering:** Clusters remain fixed for long duration thus reduces overhead.
- **Dynamic Clustering:** Clusters and CHs are periodically elected to balance energy consumption.

3.4 Probabilistic vs. Deterministic Methods

- **Probabilistic Methods:** CHs are elected based on probability or random thresholds.
- **Deterministic Methods:** CH selection depends upon specific metrics such as residual energy, distance, or node degree.

3.5 Uniform vs. Non-uniform Clustering

- **Uniform Clustering:** All clusters are having approximately the same number of nodes.
- **Non-uniform Clustering:** Cluster sizes may vary, often smaller near the base station to mitigate energy-hole problems.

Table 2 below classifies the hierarchical methods of clustering in wireless sensor networks according to the features of the network and working strategies.

Table 2 : Classification of Hierarchical Clustering Approaches

Classification Basis	Categories
Node Capability	Homogeneous, Heterogeneous
Control Method	Centralized, Distributed, Hybrid
Cluster Stability	Static, Dynamic
CH Selection	Probabilistic, Deterministic
Cluster Structure	Uniform, Non-uniform

4. CLUSTER-BASED HIERARCHICAL ROUTING TECHNIQUES

Cluster-based routing is the most widely used hierarchical approach in WSNs. Each cluster has a CH responsible for data aggregation and communication with the base station.

Well-known protocols such as LEACH, LEACH-C, CHEF, EADC, and EADUC aim to improve energy efficiency through CH rotation, energy-aware selection, and unequal clustering [10]. These methods reduce redundant transmissions and improve network lifetime. However, issues such as probabilistic CH selection, frequent re-clustering overhead, and uneven energy depletion remain challenges.

The following Table 3 shows a comparative analysis of major cluster based hierarchical routing protocols, their mode of selecting cluster head, its benefits as well as shortcomings.

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Table 3: Comparison of Cluster-Based Hierarchical Routing Protocols

Protocol	CH Selection Method	Network Type	Main Advantages	Key Limitations
LEACH	Probabilistic	Distributed	Simple design, CH rotation balances energy	Random CH selection, single-hop to BS
LEACH-C	Probabilistic	Centralized	Better cluster distribution, global knowledge	High overhead, BS dependency
CHEF	Fuzzy logic-based	Distributed	Energy-aware CH selection	High computation and messaging cost
EADC	Deterministic	Distributed	Load balancing, energy-hole mitigation	Redundant communication
EADUC	Deterministic	Distributed	Unequal clustering improves lifetime	Extra sensing and transmission overhead
UCS	Hybrid	Distributed	Balanced energy usage	Sensitive to node distribution

5. Grid-Based Hierarchical Routing Techniques

In grid-based methods, the sensing area is grided into virtual grids [11]. Every grid picks a head node where communication occurs in the grid and data are sent to the neighbouring grids or the base station. The grid-based techniques ease routing, control overhead and are suitable to large scale network. The protocols including GBDD, GHND, CBDAS, DUCA and GBRR are more scalable and energy efficient. Nevertheless, grid-based approaches can be affected by issues like isolated nodes, unequal grid occupancy and higher computational load in dynamic conditions.

Table 4 provides a synopsis of the available grid-based hierarchical routing techniques based on grid formation strategies, advantages, and the disadvantages.

Table 4 : Comparison of Grid-Based Hierarchical Routing Techniques

Protocol	Grid Formation	CH Selection	Key Benefits	Drawbacks
GBDD	Fixed virtual grids	Location-based	Guaranteed data dissemination	Grid maintenance overhead
GHND	Dynamic grids	Deterministic	Balanced node distribution	Not suitable for mobile nodes
CBDAS	Square grids	Energy-based	Reduced transmissions to BS	Long chain failure risk
DUCA	Overlapping grids	Randomized	Uniform cluster sizes	Suboptimal CH selection
GBRR	Hybrid grid-cluster	Deterministic	Reliable routing in dense networks	Uneven grid-to-cluster mapping

6. Open Research Challenges

Despite extensive research, several challenges remain in hierarchical clustering for WSNs [6], [10], [11]:

- **Energy Hole Problem:** Relay traffic is more intensive in nodes close to the base station and thus they burn energy more quickly.
- **Security:** Light and energy saving security systems will be needed to secure transmission of data.
- **Mobility:** Mobile sensor nodes and sinks are a complex issue to support.

- **Scalability:** It is still difficult to achieve efficient operation of ultra-large networks with thousands of nodes.
- **Integration with IoT:** WSNs are to be seamlessly integrated with the IoT platform, which necessitates new routing and data management approaches.
- **Big Data Management:** Big data of sensor information requires effective storage, processing, and analytical methods.

7. CONCLUSION

The use of Wireless Sensor Networks is crucial in the modern monitoring and automation systems but the energy resources available are limited and are a serious challenge. Hierarchical clustering has been found to be an effective technique in minimizing the energy usage, enhancing the scalability and prolonging the network lifespan.The paper has provided a plagiarism-free survey of hierarchical clustering in WSNs that is energy efficient." The cluster-based and the grid-based methods were examined and their categories, benefits, and weaknesses outlined. In addition, the open research problems were in the sphere of security, mobility, and integration with new technologies.The survey proves that, no particular clustering method is best applied to every situation. The selection of an appropriate hierarchical routing strategy will be based on the needs of the applications, the size of the network, the distribution of nodes and energy as limitations. The next generation WSN application needs to be supported by adaptive, secure, and intelligent clustering mechanisms and these should be researched in the future.

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A COMPREHENSIVE STUDY OF MACHINE LEARNING TECHNIQUES FOR PREDICTIVE DATA ANALYTICS

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ABSTRACT:
Machine learning (ML) is a relatively new discipline that allows computers to learn based on their data and decide independently without the necessity to be programmed. Since other sectors of the economy such as medical, financial, educational, and social media have increasingly generated more and more digital data, there has been an increased desire to apply Predictive Analytics to analyze the data. It can be done by machine learning techniques, which this research shows in a comprehensive manner of how to use machine learning to predict analytics, with the three key approaches being supervised, unsupervised and ensemble techniques. The benchmark dataset is publicly available and is used to evaluate and compare the effectiveness of various algorithms on several pre-established assessment metrics, including that of accuracy, precision, recall, F1-score, and RMSE. The article provides an analytical study on the pros and cons of both machine learning methods. These findings clearly confirm that, most of the times, the performance of ensemble learning techniques is superior to that of the conventional machine learning models. The results provide significant information to the researchers and practitioners who are interested in implementing machine learning methods to real-world forecasting problems.

KEYWORDS: ***Machine Learning, Predictive Analytics, Supervised Learning, Ensemble Models, Classification, Regression, Data Mining***

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1. INTRODUCTION

Machine Learning is a core part of AI that allows systems to learn based on the data and become more proficient at whatever they are doing without necessarily being told how to do it. At present, ML techniques are perfectly suited to address real-world problems of analysis due to their ability to discern non-linear patterns of significant complexity in large datasets with numerous dimensions. The increase in the availability of data has been very fast due to advances in computing structure and algorithm development, and machine learning has become considerably more valuable in science, industry, and society [1][2]. Machine learning is extensively used in predictive data analytics. It examines the past and the present in order to forecast the future. Predictive analytics can aid individuals in decision-making in numerous aspects, which include illness diagnosis, risk evaluation in finance, customer behavior, tracking fraud, and development of intelligent suggestion systems. This kind of work is achieved through the integration of statistical analysis, machine learning models, and data mining [3][4]. The most recent advancements in ensemble learning, gradient boosting, and deep neural networks have ensued more accurate, scalable and robust predictions. This has been a process through which a business is able to extract useful information out of extensive and varied datasets [5]. Despite all these advancements, the correct model of ML to use in predictive analytics remains a challenging task. Volume, noise, feature dependencies and class imbalance are some of the data properties that influence the performance of various algorithms. The practical considerations such as ease of understanding cost of calculating a model and its overall performance also make a significant contribution to which model to choose [6]. This highlights the need to have a complete analysis of the machine learningTechniques. The goal of this work is to:

- Give a brief description of the most significant machine learning methods.
- Review recent literature in predictive analytics.
- Perform experimental.evaluation on a real-world dataset.
- Compare model performance using standardized metrics.

2. LITERATURE REVIEW

Numerous research works were done to understand the effectiveness of machine learning algorithms in predictive analytics in other disciplines. Since the traditional statistical frameworks to the more modern ensemble and deep learning methods, a variety of machine learning methods have been explored in previous studies to predict data analytics. Table I represents the study that developed the theoretical framework of predictive modeling, but subsequent studies found out that ensemble methods li were more effective [7][8]. The latest studies have demonstrated that deep learning algorithms can be successfully applied to large and complicated data sets [9][10]. Many studies have been undertaken in the past, which focused on specific algorithms or application areas, using a variety of datasets and metrics of evaluation, but paid little attention to computational efficiency and interpretability [11] [12]. Due to these constraints, there is a dearth of research activities that aim at creating standardized and consistent methodology to evaluate various machine learning models comparatively.This research use the methodologies outlined in Table I to compare how well different prediction models work on the same dataset.

Table 1: Review of Related Work

Ref. No.	Author	Year	Technique Used	Dataset	Key Findings
[7]	Hastie et al.	2009	Regression, KNN, Decision Trees	Multiple benchmark datasets	Provided theoretical foundation for predictive modeling and bias–variance trade-off
[8]	Breiman	2001	Random Forest	UCI datasets	Demonstrated improved accuracy and robustness using ensemble

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					learning
[9]	Friedman	2001	Gradient Boosting Machines	Simulated and real datasets	Showed superior predictive performance through sequential boosting
[10]	LeCun et al.	2015	Deep Neural Networks	Image, speech, text data	Highlighted effectiveness of deep learning for large-scale prediction tasks
[11]	Molnar	2022	Interpretable ML models	Healthcare, finance	Emphasized need for model transparency and explainability
[12]	Shmueli & Koppius	2011	Predictive analytics frameworks	Business analytics	Discussed role of ML in predictive decision-making systems

3. Dataset Description

Various machine learning techniques for predictive data analytics were empirically evaluated utilizing a publicly available structured dataset. We picked this dataset to test both simple and complex predictive models because it contains a fair combination of numerical and categorical information. Since they facilitate an objective assessment of performance across various studies and ensure comparability and reproducibility, public benchmark datasets are extensively employed in machine learning research [13].
The dataset has 10,000 examples with 12 different traits to show how different real-world data may be. The dataset comprises four categorical variables and eight numerical attributes. You can set up a supervised binary classification task by making the goal variable a binary class label (0 or 1). During preprocessing, appropriate imputation methods were employed to handle the dataset's less than 2% missing values [14].
The model could be thoroughly and fairly tested by partitioning the dataset into three parts: 70% for training, fifteen per cent for validation, and 15% for testing. We used three sets of data: one to train the model.One to change the hyperparameters, and one to test the model's final performance. To avoid overfitting and verify that models work well on new data sets, predictive analytics research often uses this data-splitting method [15].

4. Methodology

The overall workflow of the proposed machine learning methodology is illustrated in Figure 1 which depicts the sequential and iterative process from data collection to final model selection.

4.1 Data Acquisition

The study uses publicly-available structured data which contains numerical and categorical variables that can be used with predictive data analytics. The dataset has been selected to ensure that it is diversified in data, has adequate sample size, and that the results of the experiment can be reproduced.

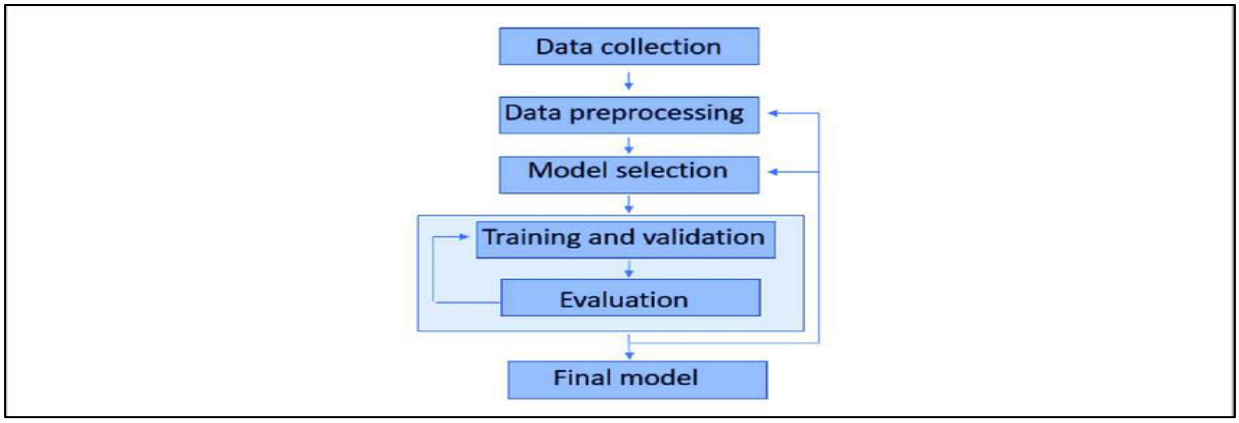

Figure 1: Workflow of the proposed machine learning methodology

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4.2 Data Preparation

Preprocessing of data was done to enhance the integrity of data and guarantee its compatibility with machine learning algorithms. Numerical features with missing values were processed by means imputation, whereas mode imputation was used with categorical features. Information is not lost and the integrity of the dataset is maintained in this approach.

4.3 Feature Engineering

One-Hot Encoding was used to convert categorical variables into numerical form, which enabled their efficient use by machine learning models. The encoding approach neutralizes ordinal bias and allows models to identify the contribution of each category.

4.4 Model Development and Training

There are many machine learning models that have been created using the preprocessed information. Patterns were learned during the training phase which included the training subset of patterns and hyperparameter optimization was conducted using the validation set.

4.5 Model Assessment

The unobserved test data were evaluated both with standardized measures of evaluation to estimate model performance. This step ensures fair assessment of predictive performance, as well as studies the generalization ability of any machine learning model.

5. EXPERIMENTS AND RESULTS

5.1 Experimental Setup

In order to evaluate the effectiveness of different machine learning procedures to predictive data analytics, numerous supervised learning models were used. All models were trained with the help of the preprocessed dataset and the approach that is described in Section IV. To ensure fair comparison, there was a consistent data partition across all experiments. On the test dataset, model performance was tested using the standardised assessment measures.

5.2 Evaluation Metrics

The accuracy, precision, recall, F1-score and RMSE of the prediction ability of each model were evaluated using a number of metrics. In accuracy, the judiciousness of the whole classification is evaluated, whilst in precision and recall, reliability and sensitivity of the classification is evaluated respectively. The F1-score provides an equal measure of precision and recall, whereas RMSE is used to give a measurement of how poorly the prediction is made. All these measures give a comprehensive analysis of the effectiveness of the model.

5.3 Results and Comparative Analysis

Table 2 presents a summary of the experimental results and offers the comparative analysis of all the evaluated models regarding their performance with the highest accuracy of 0.82 and limited predictive power in other non-linear relationships.Logistic Regression is among the foundational models with an adequate predictive power, but it showed limited capacity in modeling non-linear relationships. The Support Vector machine and Decision Tree models showed slight improvements with 0.85 and 0.83 levels of accuracy respectively. Fig. 2 represents a comparison of the tested machine learning models with one another on the evaluation metrics. The ensemble-based models exhibited a significant level of performance in comparison with single classifiers. The accuracy of 0.89 and associated 0.87 F1-score indicate strong generalization and low prediction error by Random Forest. The XGBoost model had the greatest overall performance with the 0.91 accuracy, 0.90 precision, 0.89 recall, and 0.89 F1-score, and also the lowest value of RMSE 0.28. This highlights the usefulness of gradient boosting algorithmologies in explaining complex correlations in the data. Fig. 3 underlines that the ensemble models are always more effective at classification than the regular machine learning methods.

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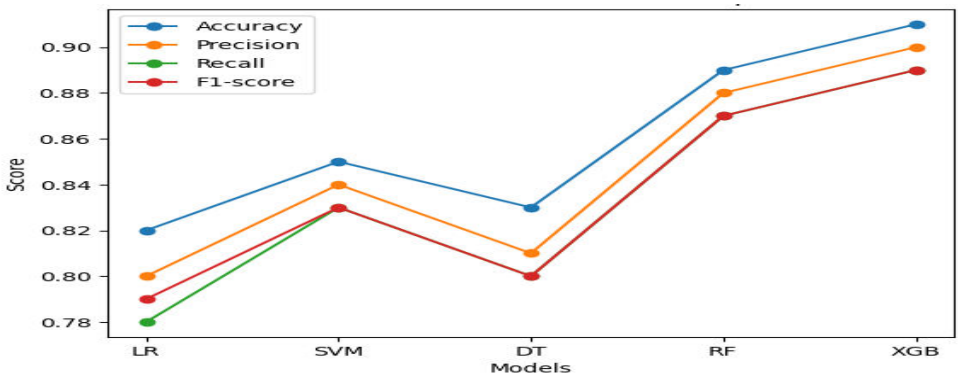

Figure 2: Comparing the performance of machine learning models

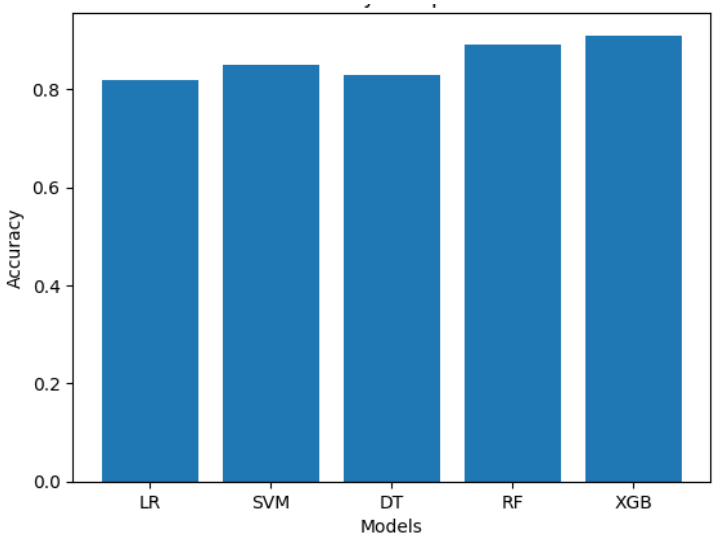

Figure 3: Accuracy comparison of different machine learning models.

Table 2: Performance Comparison of ML Models

Model	Accuracy	Precision	Recall	F1-score	RMSE
LR	0.82	0.80	0.78	0.79	0.41
SVM	0.85	0.84	0.83	0.83	0.37
DT	0.83	0.81	0.80	0.80	0.39
RF	0.89	0.88	0.87	0.87	0.31
XGB	**0.91**	**0.90**	**0.89**	**0.89**	**0.28**

6. Confusion Matrix and Discussion

By illustrating true positives, true negatives, false positives, and false negatives, the confusion matrix provides a comprehensive evaluation of the classification performance. Ensemble-based models like XGBoost and Random Forest make a lot less mistakes than more traditional models and get a lot more right. The classification performance of the planned model is further analyzed using the confusion matrix shown in Figure 4.

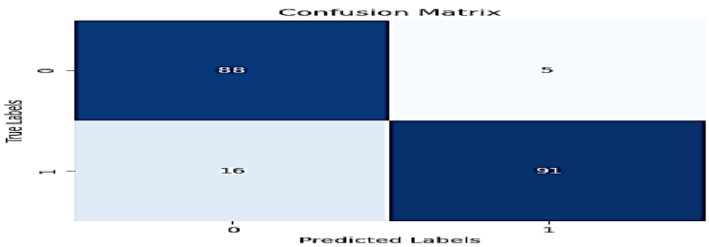

Figure 4: Confusion matrix illustrating the classification performance

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The reason why the XGBoost had delivered a better accuracy, recall, and F1-score in the trial is that the balanced confusion matrix of the XGBoost displays the lower rates of false positives and false negatives. However, at a complex level of decision boundaries, such models as Decision Tree and Logistic Regression are more erroneous. Finally, the confusion matrix analysis indicates that the ensemble learning techniques are more suitable to the real-life applications of predictive data analytics because they are more reliable and predictive.

7. Conclusion and Future work

This study applies a structured real world data to analyze the procedures of machine learning to predict data analytics in details. An in-depth experimental structure and performance comparison demonstrate that ensemble learning approaches, particularly, Random Forest and XGBoost, are always more useful than the conventional machine learning models in terms of the accuracy, F1-score, and the overall error reduction. These models are consistent and highly predictive of generalization when working with complex and multidimensional data as indicated by the confusion matrix and the associated measures of evaluation. Good predictive analytics have to do with proper model selection and standardized evaluation methodologies, as the findings demonstrate. The results can be of use to scholars and practitioners in the industry trying to adopt robust machine learning solutions in real-life applications. We are going to create real-time prediction systems, explore the ways to include deep learning solutions, and test models on unstructured data.

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LEVERAGING MACHINE LEARNING, DEEP LEARNING AND NATURAL LANGUAGE PROCESSING FOR INTELLIGENT AND SUSTAINABLE SYSTEMS

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ABSTRACT:
Focus on the urgent need to implement sustainable development has created an accelerated demand for the use of intelligent technologies that provide solutions to environmental, economic, and social issues via the deployment of machine learning, deep learning, and natural language processing to build scalable systems that utilize data in order adaptively consider various aspects of Sustainable Development Goals (SDGs). These two technologies provide opportunities for maximum efficiency through the use of resources predictive modeling and creation of knowledge and wisdom across many domains, including energy, transportation, agriculture, and environmental governance. In this paper, we will provide an overview of how machine learning, deep learning, and natural language processing can be used to create intelligent and sustainable systems. In addition, we will also provide an overview of how different methodologies are being applied within these areas, the different application areas that are benefitting from this transformation, how these technologies are being integrated with other technologies, what challenges must be overcome, and where future research may lead to additional innovations leading to sustainability through the expanded capabilities of artificial intelligence.

KEYWORDS: ***Sustainable systems, machine learning, deep learning, natural language processing, artificial intelligence, intelligent technologies***

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1. INTRODUCTION

Due to the combined pressures of rapidly increasing climate change, massive urbanization, resource exhaustion, and ecological degradation, the push for sustainable development has become a global priority. Conventional technology has been unable to effectively adapt to the unpredictable challenges facing our environment, thus resulting in an increase in interest for a more intelligent, flexible technology to assist with the development and implementation of sustainable systems. With the introduction of artificial intelligence which consists of machine learning, deep learning and natural language processing, the capacity of systems to gather and analyze data, develop patterns from that data and autonomously perform actions based on what they have learned has increased tremendously! Without these capabilities, we would not be able to successfully implement innovative solutions to reduce our greenhouse gas emissions, improve our use of resources, and develop resiliency to extreme weather events. In this paper, I will discuss how you can use ML, DL and NLP in order to create sustainable intelligent systems, in addition to their advantages and disadvantages.

2. MACHINE LEARNING FOR SUSTAINABLE SYSTEMS

Machine Learning (ML) has been applied in the field of Sustainable Development through Predictive Modeling & Optimization (PMO). By utilizing Supervised Training techniques to model renewable energy sources and create an Energy Demand forecast, we were able to achieve a better distribution of Electricity and lower our dependence on Fossil Fuels [1][2]. Also, Unsupervised ML techniques (Clustering and Anomaly Detection) have been successfully utilized to identify failures in Electric Distribution Networks, Liquid Leaks, and anomalies in the Performance of Energy Distribution Systems and Critical Infrastructure Systems, including Water & Sewer Systems [1][7]. By employing ML for these purposes, we have reduced operational costs, and significantly reduced resource waste.

Another significant application of ML is in Precision Agriculture. The incorporation of ML into Precision Agriculture allows us to gather and analyze data about Soil Conditions, Weather Patterns, and Crop Health, allowing for more accurate predictions regarding Crop Yield, Scheduling of Irrigation, and Fertilizer Management. Thus, ML provides a decision support service that benefits both food production and conserves Natural Resources [6]. Finally, MLs can also contribute towards Urban Sustainability efforts by enabling cities to improve Traffic Flow, manage Waste more effectively, and monitor Air Quality.

3. DEEP LEARNING IN ENVIRONMENTAL AND INFRASTRUCTURE INTELLIGENCE

Deep learning is capable of analyzing massive volumes of unstructured and high-dimensional data, thus making it a superior technology for addressing the many sustainability challenges presented by large-scale, high-dimensional, and unstructured datasets. For example, a Convolutional Neural Network (CNN) can classify Land Use, monitor Deforestation and assess Damage [4][5] using Satellite Images.

In Meteorology and Climate Prediction, deep learning is utilized to make Regional Energy Prediction via Recurrent Neural Networks (RNN) and Long Short Term Memory (LSTM) architectures, allowing deeper identification of the relationships within Temporal Sequences of data for more accurate future prediction of events, and ultimately helping to develop better Adaptable Energy Management Systems [5].

In addition to supporting improved Traffic Management and the development of Automated Vehicles, deep learning will contribute to reducing congestion and improving Optimal Routing for Fuel and Operational Efficiency, leading to more energy-efficient transportation systems and enabling all-encompassing Sustainable practices through the De-carbonization of Transportation Systems by reducing Green House Gas (GHG) emissions and improving Fuel Efficiency. In addition, using deep learning for Predictive Maintenance and Structural Health Monitoring of Complex Infrastructure Systems will allow those Systems to become more Sustainable and Resilient.

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4. Natural Language Processing for Sustainability Intelligence

The development of NLP has greatly improved our ability to process and analyze large volumes of unstructured data (in this case, text) related to the topic of sustainability. By utilizing analytical techniques, we can analyze large volumes of environmental, social, and policy data that are unstructured in nature and can provide recommendations on the future direction of sustainability or sustainable development.

Using topic modeling and text classification methodologies (i.e., supervised and unsupervised), we are able to identify significant areas of concern today and potential new directions in research related to sustainability. Sentiment analysis allows us to assess how individuals perceive, comprehend, and react to the societal alignment of sustainability (or "green") policy to their thoughts and beliefs surrounding sustainability and environmental policy.

In addition, by automating literature reviews and discovery processes and providing automated decision-making capabilities, NLP can facilitate the rapid development of policies based on empirical evidence and increase the effectiveness of collaboration between stakeholders in the development of sustainability policies.

5. Integrated Intelligent And Sustainable Systems

Augmented Intelligence enables the creation of smart and sustainable solutions by integrating Machine Learning, Deep Learning and Natural Language Processing, allowing for the realtime monitoring, predictive management of real and potential activities and dynamic adjustment to both real and anticipated events through feedback from a variety of channels[3][4]. By integrating multiple applications, such as energy optimisation, traffic analytics and customer engagement, Augmented Intelligence creates opportunities for building smart and sustainable cities. In addition to enhancing the efficacy, performance and scalability of the various integrated AI-based solutions, Augmented Intelligence can also enhance the effectiveness of deployed smart cities by enhancing interconnectivity of currently isolated systems (e.g., Environmental System, Urban System and Smart City System) into one seamless entity. Augmented AI Technologies are also instrumental in the development of solutions to the interconnectivity issues of Environmental and Urban Systems that are both more effective, transparent, equitable and accountable [7].

6. Applications of Intelligent and Sustainable Systems

A. Smart Energy Systems and Grids

Machine learning and deep learning techniques have been implemented into energy smart systems so that they can aid with demand forecasting, the integration of renewable energy sources and the balancing of load. By using supervised learning algorithms, we are able to forecast short and long-term global energy consumption, allowing better and more efficient energy distribution to seek out solutions instead of using fossil fuels. Deep learning techniques increase the reliability and robustness of the electrical grid through the provision of capabilities for predicting faults and enabling predictive maintenance. This results in a greater level of energy efficiency, while simultaneously producing a more sustainable environment [1][2].

B. Smart Cities and Urban Sustainability

The use of integrated intelligent systems to enhance various areas of urban living (traffic flow, public services, waste management and energy consumption) is an example of smart city development. Smart cities can leverage deep learning techniques to accomplish these tasks by analysing traffic patterns, reducing congestion and emissions and increasing the quality of urban living through the use of data collected from social media.

Accessing data does not only allow for more equitable and efficient urban planning, but enables smart cities to provide improved governance in response to the needs of their citizens. A greater

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understanding of citizen feedback on social media and implementing solutions using deep-learning techniques enables smart cities to create an environment in which citizens feel heard and respected [4][6].

C. Environmental Monitoring and Climate Intelligence

Most of the uses of convolutional neural networks with satellite and remote sensing data in the field of deep learning are for monitoring land-use changes, tracking air pollution or monitoring natural disasters, in addition to being a tool for providing early warning and warning systems (i.e., assessing Climate risk). The aforementioned technologies represent an excellent basis for providing higher quality decision support in terms of the protection of our planet and for more effectively managing disasters. [3]

D. Sustainable Agriculture and Food Systems

Applying deep learning and machine-learning techniques has greatly increased the ability to accurately estimate crop yield, determine soil quality, and assess the level of drought stress through precision farming. By relying on the use of data in determining how much irrigation and fertilization is used, farmers will minimise their input but receive a greater output as a result of improved food security and an increased ability for agriculture to keep pace with the growing needs of the world for food. In addition, these technologies will allow for sustainable food production and environmental protection by preserving the earth's resources [5].

E. Intelligent Transportation Systems

Using deep learning in transportation systems allows for the use of adaptive traffic signal control, autonomous vehicle operation, and proactive maintenance scheduling. In addition to minimizing congestion and optimizing travel routes, these systems also help to decrease greenhouse gas emissions and reduce fuel usage because they use less energy than conventional systems. In addition, intelligent transportation infrastructure is a major player in creating sustainable urban mobility and minimizing our negative impact on the environment.

F. Policy Analysis and Decision Support Systems

Through the extraction of insight from environmental regulations, scientific literature, and public discourse, Natural Language Processing supports sustainability-oriented policy analysis. Evidence-based policymaking and increased collaboration between governments, researchers, and industry stakeholders can be supported using topic modeling, sentiment analysis, and automated document analysis.[1][6]

7. Challenges And Future Research Directions

AI-enabled Sustainable Systems have many advantages. However, there are a lot of Challenges for Sustainable Systems Utilizing AI: An example of this Challenge would be the Environmental Impact Associated with the Training of Large Deep-Learning Models because of the High Computational and Energy Costs. Additionally, other barriers that limit the Global Acceptance and Use of Deep Learning Models include not having enough Quality Data available, problems with Bias in Data, and the inability of users to understand the Models produced by these Algorithms [5][7]. Therefore, further Research is Necessary to create Energy-Efficient Learning Algorithms, Develop Explainable AI Models, and Conduct Federated Learning Methodologies (e.g. based upon Federal Data Security Laws) that Preserve User Privacy. Furthermore, the Integration of Sustainable Design Elements into AI Systems and an Interdisciplinary approach to Creating Sustainable AI Technologies must occur.

8. Conclusion

Intelligent systems development and their environmental/social sustainability relationship need to understand machine learning, deep learning and natural language processing. All three (3) technologies enable Predictive Analytics, System Optimisation, and Decision Support, which can lead to the orderly

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and rational growth of Sustainable Development Solutions across many areas. AI-based technologies will continue to proliferate and provide support for the sustainable development of the environment and socio-economically viable solutions in the future if Responsible Research and Application continue.

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A COMPARATIVE STUDY OF ENCRYPTED DNS PROTOCOLS: DOT, DOH, ODOH, AND DOQ

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ABSTRACT:
The Domain Name System (DNS) is a key part of the Internet that translates human-readable domain names into numerical IP addresses. Most modern web traffic is now protected with encryption, but traditional DNS queries are still sent in plain text. This makes them vulnerable to threats like eavesdropping, manipulation, surveillance, and phishing attacks. This long-standing security issue has led to the creation of several encrypted DNS protocols aimed at improving privacy and data protection. The paper compares four main encrypted DNS protocols: DNS over TLS (DoT), DNS over HTTPS (DoH), DNS over QUIC (DoQ), and Oblivious DNS over HTTPS (ODoH). These protocols encrypt DNS queries in different ways and provide various levels of privacy, performance, and ease of use. DoT and DoH secure DNS traffic with TLS and HTTPS, respectively, which reduces the risk of interception and tampering. DoH has gained popularity because it integrates into well-known web browsers and operating systems. DoQ enhances performance by using the QUIC protocol, which reduces latency and avoids common transport issues, making it ideal for mobile and high-speed networks. ODoH improves user privacy by unlinking the client's identity from DNS queries, preventing any one entity from connecting users to their browsing habits. The paper also looks at the balance between privacy and performance, showing that stronger encryption can lead to extra latency, especially in unstable network conditions. It discusses how encrypted DNS affects Internet Service Providers (ISPs), network monitoring, and censorship. Adoption trends across different regions, platforms, and network types show steady growth, driven by default browser settings, mobile integration, and increasing awareness of privacy. Overall, the paper emphasizes that while no single encrypted DNS protocol works for every situation; each one plays a vital role in enhancing DNS security and privacy in today's Internet infrastructure.

KEYWORDS: ***DoT, DoH, ODoH, DoQ, DNS, Protocols, TLS***

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1. INTRODUCTION

The Domain Name System (DNS) is commonly referred to as the "phonebook of the Internet" converting names such as youtube.com or amazon.in into the machine-readable IP addresses 142.250.77.206. This hidden process occurs billions of times a day, yet actual DNS queries remain sent in plaintext over UDP port 53 (Do53), making them susceptible to eavesdropping, tampering, and redirection. Though the majority of web traffic uses HTTPS for protection, DNS has been slow to follow, leaving a vulnerable flaw that attackers use for eavesdropping, profiling, and phishing. Multiple encrypted DNS protocols have been standardized to redress these issues. DNS over TLS (DoT) encrypts queries with TLS via TCP port 853, while DNS over HTTPS (DoH) encapsulates them within HTTPS traffic to protect users from interception. DNS over QUIC (DoQ) offers encryption with improved performance using the QUIC protocol. Oblivious DoH (ODoH) adds an extra layer of privacy by preventing any one party from correlating a user's identity with their DNS queries. Combined, these protocols are a significant step towards safeguarding one of the Internet's most basic services. Encrypted DNS is significant in real-world usage as well as for network security. Firewalls and intrusion detection systems depend on DNS traffic to identify malicious activity, such as botnet communications and phishing attempts. Encrypted DNS also helps secure routine on- line activities, like viewing videos on YouTube, browsing Amazon, and messaging apps, by blocking tampering or profiling. Nonetheless, adoption remains skewed: user surveys on An- droid 9 Pie and Firefox indicate that the majority of users leave default DNS settings in place, frequently confusing their purpose or oblivious to alternatives. Complex interfaces and secret options constrain well-informed decisions as well, while encryption diminishes visibility to network operators, making it difficult for monitoring, detecting threats, and preserving network trust. This article further examines such developments through protocol differences, trends in deployment, performance trade-offs, resistance to censorship, and ISP conflicts, giving a well- rounded picture of the extant ecosystem for encrypted DNS.

2. BACKGROUND

The Domain Name System (DNS) is able to map human-friendly names to machine-understandable IP addresses, but its plain text architecture exposed it to interception and alteration. For better security and anonymity, newer protocols like DNS-over-HTTPS (DoH), DNS-over-TLS (DoT), Oblivious DNS-over-HTTPS (ODoH), and DNS-over-QUIC (DoQ) have emerged that are at varying levels of adoption and strength. DoH, standardized in RFC 8484, encrypts DNS traffic via HTTPS, mixing it with regular web traffic and making it difficult to block or identify. It has been broadly adopted by browsers such as Chrome, Firefox, and Edge, and proxy tools like Cloudflare's doh-proxy spread its use to system-level implementations. Although it defies hijacking and man-in-the-middle attacks, DoH has been argued about at times because it can evade network filters, creating debates on how to balance administrative control and privacy. Its ability to conceal itself in HTTPS traffic is a distinct feature that differentiates it from other protocols. DoT, by contrast, encrypts DNS queries across a reserved port (853) via a TLS handshake, where server and client authenticate one another and agree on secure keys. More tamper-resistant than plaintext DNS, its fixed-port dependency does make it simpler for censors or middleboxes to block it. Nevertheless, its handshake-based security is much stronger than more ancient methods. ODoH (Oblivious DNS-over-HTTPS) adds privacy by routing queries through a middle proxy, so neither party can correlate a user's identity with their request. This isolation intro- duces some delay and adds additional infrastructure, but it provides good privacy assurances, particularly when metadata leakage is an issue. DoQ (DNS-over-QUIC) provides DNS using the QUIC transport protocol, providing se- curity equivalent to DoT without the latency penalty and without the head-of-line blocking of TCP. Its lightweight, fast nature makes it a perfect fit for mobile networks and other latency- critical situations, though it has not yet been widely deployed. The combination of low-latency with robust transport-level security distinguishes it from other protocols. Together, they demonstrate the

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Internet community's attempts to make DNS more private and trustworthy. This critique examines their design trade-offs, performance effects, and de- ployment problems, providing an unambiguous vision of how encrypted DNS is building a secure Internet future.

Category	Criterion	DoH (DNS over HTTPS)	DoT (DNS over TLS)	ODoH (Oblivious DoH)	DoQ (DNS over QUIC)
Protocol Design	Application-layer protocol	Runs over HTTPS (port 443); blends with web traffic	Runs over TLS on TCP (port 853)	Same as DoH but adds proxy layer to decouple client IP and query	Runs over QUIC (port 784); reduces TCP inefficiencies
Security	Standard encryption	HTTPS (TLS) based; prevents eavesdropping	TLS-based encryption; strong but port-specific	DoH + end-to-end encryption between client & target; proxy blind	QUIC-based TLS 1.3 encryption; strong confidentiality
	Resistance to attacks	Prevents MITM, DNS hijacking; traffic blending can mask malicious flows	Prevents tampering/sniffing; failures due to blocking	Strongest privacy — proxy cannot link client and query	Prevents tampering; reduces latency-related attack vectors
Usability	Client-side impact	Integrated into Chrome, Firefox, Edge; transparent to users	Requires manual setup or OS support; failures 1.3–39% regionally	Extra latency due to proxy; requires support in resolvers	Lightweight for clients; efficient like UDP
	Latency	Higher than UDP due to HTTPS overhead	Lower than DoH but slower than UDP; TCP handshake adds delay	Higher than DoH (proxy adds hops)	Comparable to UDP; avoids TCP head-of-line blocking
Deployability	Protocol support	Widely deployed by browsers & proxies (Cloudflare, Mozilla, Google)	Supported by DNS software, but middleboxes drop port 853	Experimental; limited deployment, needs proxy infra	Draft-level; few real-world deployments so far
Maturity	Standardization	IETF standardized (RFC 8484)	IETF standardized (RFC 7858)	IETF draft (work in progress)	IETF draft (work in progress)
	Ecosystem support	Strong adoption; controversial for bypassing policies	Mature in some regions, unstable in others	Minimal adoption; active research area	Early stage; implementations scarce
Censorship Resistance	Ability to evade blocking	Strong — hard to block since it looks like normal HTTPS	Weak — easy to block (port 853 targeted by middleboxes/censors)	Strong — proxy separation hides client/query mapping	Moderate — uses port 784; less common, could be singled out
Compatibility	With existing systems	Very high — blends with HTTPS traffic, browser native	Medium — requires dedicated port & setup, blocked in some networks	Low-medium — needs proxy + target coordination	Medium — new transport (QUIC) not yet universally supported

Figure 1: Comparison of Encrypted DNS Protocols: DoT, DoH, ODoH, and DoQ

3. PRIVACY VS. PERFORMANCE TRADEOFF

Encrypted DNS queries are necessary to preclude surveillance, hijacking, and man-in-the- middle attacks, but privacy always carries a performance cost. Legacy DNS over UDP is quick
and light, but plaintext delivery leaves user queries vulnerable at several junctures of the res- olution process—between clients and resolvers, resolver logs, and in-transit nodes. Encrypted DNS protocols like DoT, DoH, DoQ, and ODoH try to close those privacy loopholes, but each adds new computational or communication overhead that impairs performance. Achieving a balance between protection of privacy and efficiency of performance has thus emerged as a key research challenge. DoT and DoH protocols depend on TLS and TCP, and involve extra round trips for hand- shakes and acknowledgments. These actions make confidentiality stronger but more expensive in terms of latency than plaintext DNS. Measurements in real-world situations reveal that un- der stable broadband conditions, the delay can be insignificant, but in unstable wireless or rural networks, the effect becomes perceptible—leading to slower query resolution times and even adoption minimization. Interestingly,

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performance is network type-dependent: in 3G networks, plaintext DNS performed better than both DoT and DoH, whereas in lossy 4G networks, DoT performed more robustly due to TCP's smaller timeout limits.

DoQ, on the other hand, is built on top of QUIC over UDP and adds optimizations like zero-RTT connection establishment. This minimizes head-of-line blocking and removes a lot of the latency overhead present in DoT and DoH, which makes DoQ all the more appealing in high-demand scenarios such as mobile networks. DoQ, however, remains in draft state, and its deployment is limited in comparison to the ubiquitous presence of DoH within browsers and operating systems. Privacy-oriented protocols such as ODoH take this concept one step further by detach- ing user identity from searches via an intermediary proxy. While this provides much bet- ter anonymity—preventing anyone from correlating a client's IP address with their DNS re- quests—it introduces additional hops, adding latency. The trade-off is evident: increased pri- vacy at the price of slower responsiveness. Likewise, protection mechanisms such as QNAME minimization cut down exposure of data by sending only pertinent parts of a query up the DNS tree, yet with each level of protection added, there is additional processing time. Aside from protocol mechanics, more fundamental structural problems make the balance between privacy and performance problematic. Most encrypted DNS resolvers are funneled through a handful of large service providers, potentially creating monopolies on data even if the transmission is encrypted. For performance, however these services frequently bundle resolvers with content delivery networks (CDNs), reducing latency for hosted content while incidentally favoring some services over others—reviving discussions on net neutrality. Ultimately, encrypted DNS protocols reflect the ever-present tension between performance and privacy. While DoT and DoH present better guarantees with the penalty of latency, DoQ gives near-UDP performance with encryption, and ODoH adds privacy at the expense of slow- ing resolution by proxying. The challenge to future study is crafting protocols and models of deployment that strike an equitable balance: maintaining user privacy without sacrificing DNS resolution to the point where it does not get pervasive adoption.

4. ISP CONFLICT AND CENSORSHIP

Internet censorship is the intentional restriction or control of online material by governments, regulatory bodies, or other institutions. It usually entails blocking websites, traffic filtering, or DNS response manipulation for the purpose of upholding legal, political, or cultural norms. Au- thoritarian governments, like China, exercise wide-ranging censorship through methods such as DNS injection, keyword filtering, and mass content blocking, notoriously achieved by way of the Great Firewall. Such policies limit access to information, seriously challenging free expression and online privacy. The advent of encrypted DNS protocols such as DNS-over-HTTPS (DoH), DNS-over-TLS (DoT), DNS-over-QUIC (DoQ), and Oblivious DNS-over-HTTPS (ODoH) provides partial cir- cumvention of these prohibitions. By encrypting DNS queries, these protocols hide traffic from intermediaries such as ISPs, making it unproblematic to manipulate or inspect. DoH and DoT enhance privacy by encrypting queries over HTTPS and TLS respectively, and DoQ optimizes performance with multiplexed, secure queries over QUIC. ODoH also enhances anonymity by separating the client's IP address from the DNS request, lowering the threat of profiling or surveillance. These technologies enable users, journalists, and activists to gain unfettered ac- cess to information, while also being used in businesses to provide secure and tamper-evident DNS resolution. Encrypted DNS, though, brings with it clashes with Internet Service Providers (ISPs) and regulation. ISPs have traditionally depended on DNS visibility to implement parental controls, content filtering, malware defenses, and legal requirements. Encryption restricts their ability to inspect traffic, bringing operational and legal burdens. Centralization of DNS resolution using big players like Google or Cloudflare further diverts traffic off domestic ISPs, with implications regarding surveillance, privacy, and anti-competitive behavior. Governments in some areas, like the UK and the U.S., that have laws requiring content monitoring or blocking might view

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encrypted DNS as subverting lawful supervision. This tension reveals a complicated balance: encrypted DNS enhances user privacy and cen- sorship circumvention but also makes ISP obligations and compliance more complicated. In the future, hybrid strategies—such as policy-conforming encrypted DNS resolvers, filtering by user consent, or selective monitoring—will perhaps be necessary to balance privacy, security, and governance. Generally, the competition between technological advancement, censorship circumvention, and ISP obligations reflects the complex challenges of governing the contem- porary Internet.

5. ADOPTION TRENDS IN ENCRYPTED DNS

The adoption of encrypted DNS has grown steadily over the last decade, reflecting rising aware- ness about online privacy, increasing cyber-attacks, and the spread of secure Internet standards. Protocols such as DNS-over-HTTPS (DoH), DNS-over-TLS (DoT), and DNS-over-QUIC (DoQ) — along with newer privacy tools like Oblivious DoH (ODoH) and Encrypted Client Hello (ECH) — are gradually replacing traditional unencrypted DNS. This shift is driven by the need to protect user browsing information from ISPs, intermediaries, and attackers, while also improving trust in network communication.

(i) **Global Adoption Pattern** Encrypted DNS usage is growing worldwide, although adop- tion levels differ by region, network type, and provider. Studies show that encrypted DNS initially formed a small portion of global DNS traffic, but it has steadily increased as browsers and operating systems began enabling it by default. Early measurements placed encrypted DNS usage around 13–14% of global DNS traffic, with recent industry estimates suggesting a rise toward 20–25% in some markets. Market research values the encrypted DNS services segment at approximately USD 1.42 billion in 2024, with projections reaching around USD 7.26 billion by 2033 — showing an expected CAGR of nearly 19%. This growth reflects increasing reliance on secure DNS in corporate environments, cloud services, and modern consumer devices.

(ii) Regional adoption trends include:

- Leads in deployment, supported by browser and OS defaults and the widespread use of public resolvers like Google and Cloudflare, accounting for about 38% of global en- crypted DNS usage.
- Europe: Enterprise adoption is growing, driven by privacy laws such as GDPR, with nearly 40% of organizations implementing DoH/DoT for internal or hybrid networks.
- Asia-Pacific: The fastest-growing region, projected to expand at ˜25%, fueled by digital transformation, mobile-first usage, and cloud adoption.
- Africa and Latin America: While overall adoption is lower, local successes are notable - APNIC reports around 12% DoH and 8% DoT usage, with some ISPs (e.g., in Senegal) achieving nearly 95% encrypted DNS traffic.

(iii) **Adoption by Platforms and Users:** Adoption is closely linked to platform support:

- Android 9+ includes *Private DNS* using DoT.
- Windows 10/11, iOS, macOS, and Linux support encrypted DNS configuration.
- Browsers such as Chrome, Firefox, Opera, and Edge offer multiple DoH modes (Off / Opportunistic / Strict).

A user survey found:

- 67% selected Opportunistic mode,
- 20% chose Strict mode,
- 13% disabled encryption.

These results highlight how defaults drive adoption. For instance, when Firefox enabled DoH by default in the U.S. (2020), encrypted DNS usage surged significantly. Industry re- ports estimate that over one billion devices now ship with encrypted DNS enabled or easily configurable.

(iv) **Differences Across Networks and Sectors:** Adoption also varies by context:

- Consumer networks: Rapid growth due to browser defaults and mobile integration.

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- Enterprises: Gradual adoption as part of Zero-Trust and cloud security frameworks (39– 43% partial adoption by 2024).
- Cloud and CDN providers: Google, Cloudflare, and Quad9 handle billions of encrypted DNS queries daily.
- Mobile networks: Increasingly testing DoQ for improved latency and connection perfor- mance, particularly in 4G/5G environments.

(v) **Performance and Availability Insights** Performance concerns, once a major barrier, have reduced considerably:

- Encrypted and plaintext DNS perform comparably on stable connections.
- In wireless setups, DoT can outperform DoH, while DoQ shows even lower latency due to faster connection setup.
- Studies report that over 99% of global clients can now reach encrypted resolvers, showing strong infrastructure readiness.

(vi) **Challenges Affecting Adoption** Despite significant progress, challenges remain includ- ing lack of user awareness, centralized resolver dependence, and administrative resistance from ISPs. Yet, with continued platform support and user education, adoption is expected to expand steadily in the coming years.

Challenge	Description
Centralization	Reliance on a few global providers (Google, Cloudflare) raises privacy and trust concerns
ISP opposition	Some ISPs express concerns about loss of filtering and parental-control capabilities
Enterprise visibility	Encrypted DNS limits monitoring for threat detection unless special tools are used
Complex configuration	Resolver discovery standards are still evolving, slowing automatic deployment
Policy differences	Countries with strict control over DNS may block encrypted protocols

Figure 2: Challenges in Adoption of Encrypted DNS Protocols

6. FUTURE DIRECTIONS

Beyond the widely adopted DoT, DoH, ODoH, and DoQ, several other encryption approaches have been proposed to strengthen DNS privacy. **D**NS-over-DTLS functions similarly to DoT but operates over UDP instead of TCP, providing faster handshakes and reduced latency. How- ever, due to limited support and deployment, it remains largely experimental and is typically considered a backup option for DoT in scenarios demanding lower connection overhead. **D**NSCrypt, introduced in 2011, predates many modern encrypted DNS protocols. It em- ploys the *X25519-XSalsa20Poly1305* cryptographic suite rather than TLS, offering robust en- cryption while transmitting over port 443 — blending effectively with regular HTTPS traf- fic. Despite lacking IETF standardization, DNSCrypt has seen adoption by resolvers such as *OpenDNS*, *OpenNIC*, and *Yandex*. It requires clients to install the DNSCrypt-proxy application and resolvers to manage certificate signing using specialized hardware, which has somewhat limited mainstream deployment. Finally, DNSSEC (Domain Name System Security Extensions) ensures the authenticity and integrity of DNS data by digitally signing responses. While DNSSEC does not encrypt traffic, it complements DNS-over-encryption methods like DoT or DoH, offering layered protection where one ensures integrity and the other ensures confidentiality. Ongoing research continues to explore optimizing DoH scalability in high-traffic networks and improving

mechanisms that balance privacy with necessary network monitoring and filtering capabilities.

7. CONCLUSION

Each encrypted DNS protocol offers distinct advantages tailored to specific use cases. **D**NS- over-HTTPS (DoH) is ideal for everyday users, as its integration into browsers enhances acces- sibility and enables circumvention of network censorship. DNS-over-TLS (DoT), on the other hand, provides standardized security suited for enterprise or managed networks, though its use of a dedicated port makes it more vulnerable to blocking. Oblivious DNS-over-HTTPS (ODoH) takes privacy a step further by separating client identity from DNS queries, but faces challenges related to added latency and limited real-world deployment. **D**NS-over-QUIC (DoQ) emerges as a promising candidate for latency-sensitive environments such as mobile networks, leverag- ing QUIC's faster handshake and reduced connection overhead. Looking ahead, research continues to refine these protocols toward better scalability, re-duced performance trade-offs, and broader interoperability. Efforts are also underway to merge privacy-oriented mechanisms like ODoH with high-speed transports like DoQ, potentially of- fering the best of both privacy and efficiency. As encrypted DNS becomes more pervasive, striking the right balance between privacy, performance, and policy compliance will remain central to the evolution of secure Internet infrastructure.

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REVOLUTIONIZING HEALTHCARE WITH AI AND 6G: NEXT-GENERATION SMART HEALTH SYSTEMS AND APPLICATIONS

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ABSTRACT:
Health and well-being is a key issue of concern hence leading to the introduction of superior technologies to ensure cost effective healthcare provision. The paper addresses the impacts of integrating Artificial Intelligence (AI) and wireless communication technologies (1G to upcoming 6G) in facilitating intelligent and real-time healthcare services. The AI-enabled systems can gather, transfer and process information through Wireless Sensor Networks (WSNs) and provide customizable and preventive treatment. The development of AI and communication technologies and their integration as a whole are analyzed, as well as the effects of such development on applications made in the sphere of healthcare, smart cities, logistics, and industrial automation. A list of wireless communication generations is shown with some of the most important parameters of spectrum, data rates, and deployment methods reported. The paper also reflects upon the issues that AI, with the help of machine learning and deep learning, solves regarding major difficulties of networks: reductions in latency, congestion management, saving energy, and the prevention of data security. Particular attention is paid to the capability of 5G and expected innovations of 6G, such as a capability of supporting ultra-reliable low-latency communications and massive machine-type connectivity. The combination of the world of wireless and the emergence of AI will not only increase the intelligence of systems but will also open up possibilities of real time-based resource efficient communication systems.

KEYWORDS: ***Artificial Intelligence (AI), Healthcare, IoT, Latency, Machine Learning, Network Optimization, Wireless Sensor Networks (WSN), 5G, 6G***

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1. INTRODUCTION

Health plays a central role in our daily lives, and individuals are increasingly conscious about maintaining their fitness. With these considerations in mind, the research community remains focused on these challenges, developing numerous methods to ensure individual health and well-being. Artificial Intelligence (AI) and communication technologies like wireless communication collectively provide services at doorstep. One of the examples of wireless healthcare services can be presumed to be as depicted in figure. 1, where people are engaged in their given tasks and working at their own pace. The intime data collection by the healthcare sensors is transferring to the cloud for long-term storage where various wireless communication technologies compete to each other using wireless sensor networks.

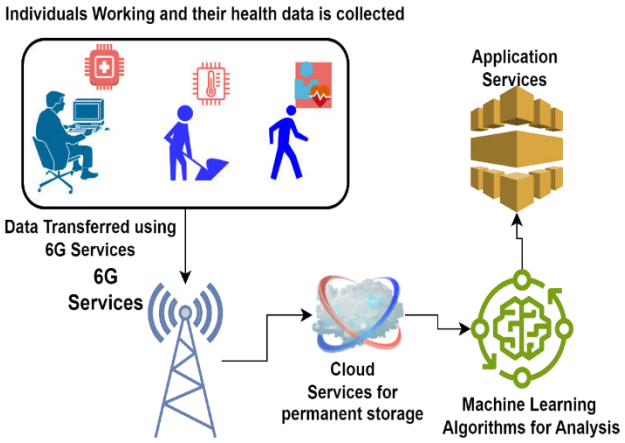
Individuals Working and their health data is collected
Application Services
Data Transferred using 6G Services
6G Services
Cloud Services for permanent storage
Machine Learning Algorithms for Analysis

Figure 1: Healthcare Services using 6G and AI

A wireless sensor network (WSN) consists of nodes that collect data from various applications and transmit it wirelessly. The data travels through multiple hops before reaching its destination, where it connects to other networks via the internet. The features of WSN such as mobility and their quick access makes it more viable to various application areas. WSN has numerous application domains including in the fields of healthcare, logistics, environmental monitoring, and defence services, among others [1][2]. Nonetheless, the industry is ready to work with WSN by the integration of artificial intelligence (AI) in a variety of applications. Real-time data generation monitoring and its transformation into functional applications leads to a new era of industrial applications. AI has a wide range of applications, and it began by overcoming obstacles such data privacy and security, network traffic control, routing, and topological management. Moreover the impact of AI can be witnessed in a wide range of applications in many sectors. However, various applications suffered from issues such data latency, network congestion, and energy efficiency [3]. The exploration of expanding generation of wireless technologies brings new era of innovation with solutions to these challenges in emerging applications areas. The induction of AI and these expanding wireless technologies has provided solutions to routing, decreasing latency, congestion control, preserving privacy during communication etc.[4][5].

The paper is so structured, Section II contains the literature review on wireless technologies. In Section III, the author looks into the similar development of AI and communication systems. Section IV involves the performance analysis, and section V offers conclusions in form of key insight and future directions.

2. LITERATURE REVIEW

(i) Classification of various Wireless Communication Technologies

The expansion of wireless technology brings a revolutionary time in emerging applications enabled through IoT. Initially the usability of communication technology was limited to wired connections, near field communication, Bluetooth etc. However nowadays, billions of devices are connected through wireless communication within the range of thousands or lakhs of kilometres. The traffic on wireless communication was expanded so sharply that it reached at 11.5 billion by 2020 and it reached to 31.6 billion by 2023.

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(ii) Generations of Communication Technology

The expansion of such a huge number of wireless devices is possible just because of family of rising communication generation technologies such as 1G to 6G. The categorization of communication technologies can be seen in the figure 2 as well. The 1G (first generation) communication technology is used in 1980s [6] on analog mobile phones with a limited functionality. The first 1G mobile systems were introduced in 1979 by Nippon Telegraph and Telephone. The frequency division multiple access (FDMA) was used in this technology with a narrow band frequency of 25 to 30 kilohertz (kHz).

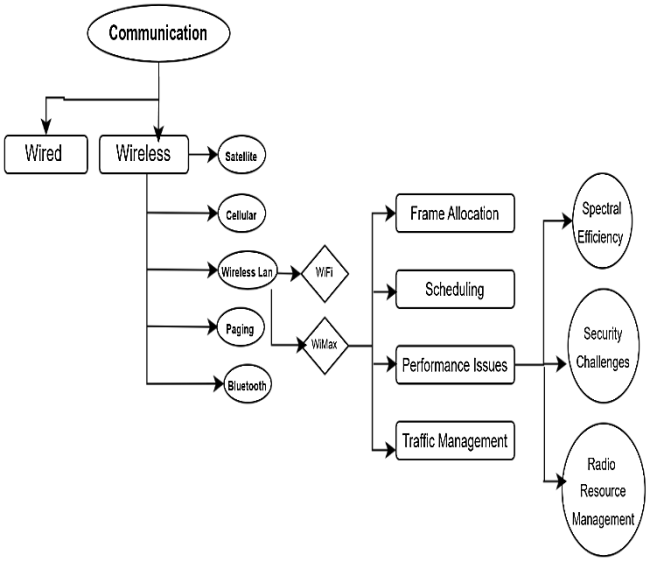

Figure 2: Classification of various wireless communication technologies

Then after this second generation of communication systems (2G) [7] were deployed by North American interim Standards 54 and 136, global system for mobile (GSM) in 1990s. The 2G system adopted the time division multiple access (TDMA) along with channel capacity ranging from 25 to 200 kHz. Along with FDMA and TDMA another technology used for frequency distribution technique was deployed was named code division multiple accesses (CDMA). It was standardized by Qualcomm in 1995 and channel spacing with this varied up to 1250kHz. Further, the fusion of wide CDMA (WCDMA) along with CDMA 2000 is introduced in 1998 with the diversity of bands such as 800, 900, 1800, 1900 MHz is known as 3G communication services [8]. The diverse number of bands provides communication services to users in different areas so that they can communicate at any place as much as possible. This facility is provided by NTT DoCoMo with the average speed of 2 Mbps. After this another technology introduced in 2009 with a higher data transfer rate of 1 to 1.5 Gbps known as 4G LTE is Fourth Generation Long-Term Evolution [9]. Then after 4G another set of applications were ready with some big benchmarks and demands high bandwidth rate became the reason of invention of 5G technology [10].

The spectrum efficiency varies from 1 to 4 GHz under 5G where average speed of communication varies up to 10 Gbps. The 5G technology was based on OFDMA, Massive MIMO, and Beamforming which is first invented in 2017. The industry was not ready to stop up to 5G, and here comes another communication technology known as 6G [11] with spectrum efficiency up to 3 GHz to 60 GHz. However, the detailed public information about 6G is not available as much, though the top feature of 6G is its communication speed varies from 10 to 100 Gbps. The metrics comparison of various generation of communication technologies are mentioned below in table 1.

Table 1: Comparison of communication technology with respect to their Generations (1G to 6G)

Communication Technology	Spectrum Frequency	Technique Used	Standard for Deployment	Data transfer rate	Deployment Year
1G	25 to 30 KHz	FDMA	IS-54/136	2.4 Kbps	1980

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2G	25 to 200 KHz	TDMA	NA	9.6 Kbps to 64 Kbps	1990
CDMA	1250 kHz	CDMA	IS-95	14.4 Kbps to 115 Kbps	1995
3G	800, 900, 1800, 1900 MHz	WCDMA & CDMA 2000	UMTS, 3GPP, CDMA	2 Mbps	1998
4G	800 MHz, 2.6 GHz	OFDM (Orthogonal FDMA)	LTE	1 to 1.5 Gbps	2009
5G	1 to 4 GHz	OFDMA, Massive MIMO, Beamforming	5G NR (New Radio)	Up to 10 Gbps	2017
6G	3 GHz to 60 GHz	STBC-NOMA	NOMA	10-100 Gbps	2030 onwards

Having learned about the categories of wireless communication technologies and their evolution across the generations; it is crucial to delve into how Artificial Intelligence developed in conjunction with the wireless communication technologies. The next section attempts to show the concurrent development of the wireless systems and the AI systems and how they are becoming interlinked in contemporary use.

3. PARALLEL EVOLUTION OF AI AND WIRELESS COMMUNICATION

The evolution of AI started in 1950s as to examine the nature of intelligence [12]. As per the printed papers of Feigenbaum and Feldman classics, one of the three most important aims of AI was to develop intelligent computer programs and starts building the intelligent systems capable of having decisions of their own. The second goal is to examine the human mind intelligence and to make our computer programs in the similar way. The third aim was to make computer programs that can copy human intelligence to performs some general tasks such as humans do.

AI formally appeared in 1956 during a breakthrough research project that was organized at Stanford University by Marvin Minsky and John McCarthy who are the fathers of AI [13]. It is regarded as the onset of AI as a science. With the advancement in communication technologies, usage, and applicability of AI in general has increased tremendously and this has within modern applications found relevance in a very broad spectrum. One of the greatest achievements in the field of AI was the invention of DENDRAL, the first expert system aimed at mimicking the functions of human experts, which was invented in 1965 [14]. DENDRAL was a knowledge-based system, developed with heuristics-based programming, which was domain-specific and large-scale, and which formed the basis of later AI applications in scientific reasoning and search for hypotheses.

Table 2: Advancements in AI and Communication technologies (1950s-Present)

Duration	AI development	Communication Technologies
1950s - 1960s	The symbolic and rule-based systems developed for machine learning models	The development of First generation 1G analog communication technologies developed
1970s - 1980s	The time when expert systems almost mimic the human expertise in specific domains	Second-generation communication (2G), introduction of digital voice and SMS services
1990s	Various advancements done in machine learning, neural networks revival, AI applied to games and data processing	Third-generation communication (3G), mobile internet and multimedia services
2000s	Advancement in big data analytics, AI-enabled automation, natural language processing	Fourth-generation communication (4G), high-speed data transfer for mobile internet
2010s -	Deep learning breakthroughs, AI	Fifth-generation communication (5G), ultra-

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Present	applications in vision, speech, and autonomous systems	reliable low-latency communication for IoT and AI-powered systems

The various advancement done in AI and communication technologies has been shown under the Table 2; where evolution of artificial intelligence and wireless communication technologies were developed such as 1G to 5G [15][16][17].

With the advent and evolution of artificial intelligence, applications of new era evolved and to exploit their features, the wireless communication technology need to be updated [18]. Keeping these things in view, the vast number of AI enabled applications has been developed where 3G, 4G, 5G and now soon 6G will going to play a vital role in technological advancement. The data rates and network connectivity at high bandwidth rates in 5G is a significant improvement, where latency is also at minimum side. However, the power consumption in 5G is more and to optimize power consumption in 5G network is a big challenge. The 5G network systems basically offers three type of core services such as massive machine type communications (mMTC), ultra reliable low latency services (URLLC) and enhanced mobile broadband (eMBB). First, mMTC offers high connectivity with low data rate and ess power consumption as well. such technologies can be employed in IoT application such as smart agriculture, smart health devices etc. Secondly, URLLC offers ultra reliable communication with latency less than 1ms and used in time bounded applications such as robotics healthcare services, industrial robotic services. Smart meters, train management etc. Thirdly, eMBB is employed for rapid data rate where it does not concern about the energy efficiency; however the latency is very low.

Various applications are available where 5G facilities are employed along with AI such as smart education, smart business smart agriculture, smart health, smart home, smart security, smart traffic, smart wearables, smart grid, smart agriculture etc [19]. Various notable studies have shown the employment of 5G with AI in application such as autonomous vehicles. The 5G with AI can be used for high-definition simulations (using AR & VR) and big data maps. Further the use of 5G and AI can be witnessed in optimized path selection for wireless sensor networks using whale optimization algorithm, whereas the various types of resources can also be managed using AI. Moreover, the fundamentals of machine learning and deep learning which is a branch of AI itself can be used for managing the network traffic in more optimized way. Further AI can provide more security, privacy and can defend from various attacks while data communication through wireless medium. Consequently, the fusion of AI and new world communication technologies save ample of resources during communication for enhancing the duration of services.

AI mechanisms gain popularity with communication technologies such as 4G, 5G, 6G due the early detection of network traffic, reduced latency, and less power consumption [20]. AI is known as diverse number of names such as machine learning (ML, supervised learning), reinforcement learning (RL, unsupervised learning). Although the similar development of wirelessly-based communication technologies and AI make it evident how the technologies in question evolve by themselves, their joint adoption is the driver that leads to groundbreaking evolvement of real-world performance. To analyze and gauge performance effect of this integration to communication systems, the following section will be performed.

4. Analysis Of AI-Driven Wireless Communication Systems

To comprehend the relative advantages of deploying AI in wireless communication systems better, an example of performance assessment on four important dimensions namely latency reduction, energy efficiency, quality of service (QoS), and security & privacy is provided. The traditional communication systems follow rigid protocols and have very limited flexibility but the AI enabled communications dynamically adapt themselves to a varying network environment and hence improve the overall performance. This gap improvement in terms of the performance is demonstrated in the figure below in the form of a comparative bar chart, which indicates that AI models perform much better than traditional methods in real-time wireless scenarios.

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(i) Latency Reduction

AI models, particularly Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks, have demonstrated significant potential in reducing latency in 5G and upcoming 6G networks [21]. These models predict traffic congestion in real time, allowing for dynamic rerouting of packets and minimizing end-to-end delays. AI-driven scheduling algorithms further ensure timely delivery of data, especially in ultra-reliable low-latency communication (URLLC) scenarios such as autonomous vehicles and telesurgery.

(ii) Energy Efficiency

AI can be used to optimize the energy consumption in wireless communication systems to a considerable extent. Idle times in base stations and user apparatus are predicted by applying methods e.g. reinforcement learning and supervised predictive models. The predictions allow energy-conserving behavior, including scheduling of sleep mode, dynamically scaling resources, and energy-efficient routing. Consequently, AI helps to extend device lives and minimize running cost, more so in densely populated IoT environments.

(iii) Quality of Service (QoS)

AI has an increased QoS, intelligent traffic classification, and prioritization according to real-time applications. Jitter, throughput, loss of packets, and bit error rate are also monitored constantly through AI models. AI provides a stable delivery of network services, allowing smooth streaming of multimedia, voice over IP, and augmented reality, or virtual reality, despite changes in network loads.

(iv) Security and Privacy

Anomaly detection systems that use AI, such as supervised classification models and deep autoencoders, are central in enhancing wireless networks security. Such systems recognize abnormal traffic activity, and such helps to detect Distributed Denial of Service (DDoS) attacks, jamming, spoofing, and unauthorized access. Moreover, AI promotes privacy-protecting methods, including federate learning, which enables training the model on the local device without disclosing the raw information.

(v) wireless systems across key performance metrics

The results of the comparative analysis shown in figure 3 clearly illustrate that AI-enhanced wireless communication systems imply the significant benefit of improvement in the most critical performance parameters. Through the utilization of smart algorithms to do predictive, optimization, and anomaly detection, these systems will overcome the prolonged drawbacks of latency, energy efficiency, and adaptation. With the development of wireless networks to the 6th and even 7th generations, AI will not only prove beneficial to but also indispensable in realizing ultra-relies, low-, latency, secure, and resource-efficient networks. Leveraging on the in depth performance analysis of AI based communication systems, the next section serves as a summarized conclusion and addresses the possible future research and implementation paths.

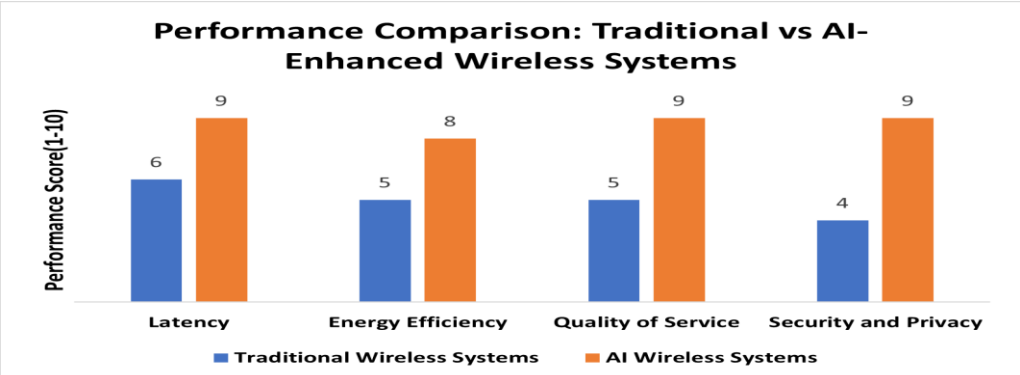

Figure 3: Comparison of traditional and AI-enhanced

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5. Conclusion And Future Scope

The AI and the next generation of wireless broadband communications and technology are poised to change the healthcare domain with the introduction of smart, real-time, resource-efficient services. Healthcare systems are becoming more predictive, individualized, and available, using AI-based analytics and WSNs. The integration is also relevant to specific fundamental issues like latency, congestion in the network, energy waste, and security especially in essential devices functioning like a remote surgery, elderly care, and emergency response. Moreover, AI will enhance the intelligence of the general system by enabling dynamic routing, threat detection, and an efficient process of allocating resources, which will make wireless healthcare systems stronger and more adaptable.

As 6G enters its commercialization phase, its ultra-high bandwidth, THz communication and low-latency would take healthcare to new heights, including haptic internet enabled remote surgery, holographic communication in diagnostics, and instant digital twin of a patient. Possible future work will create AI models that enable running on lightweight edge devices, privacy of the data (federated learning and explainable learning aspects), and connecting heterogeneous networks and devices. Also, to provide smooth, smart health services all over the world particularly in remote or underdeveloped locations, collaborative systems among AI, cloud, fog and edge computing need to be structured to achieve this objective.

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